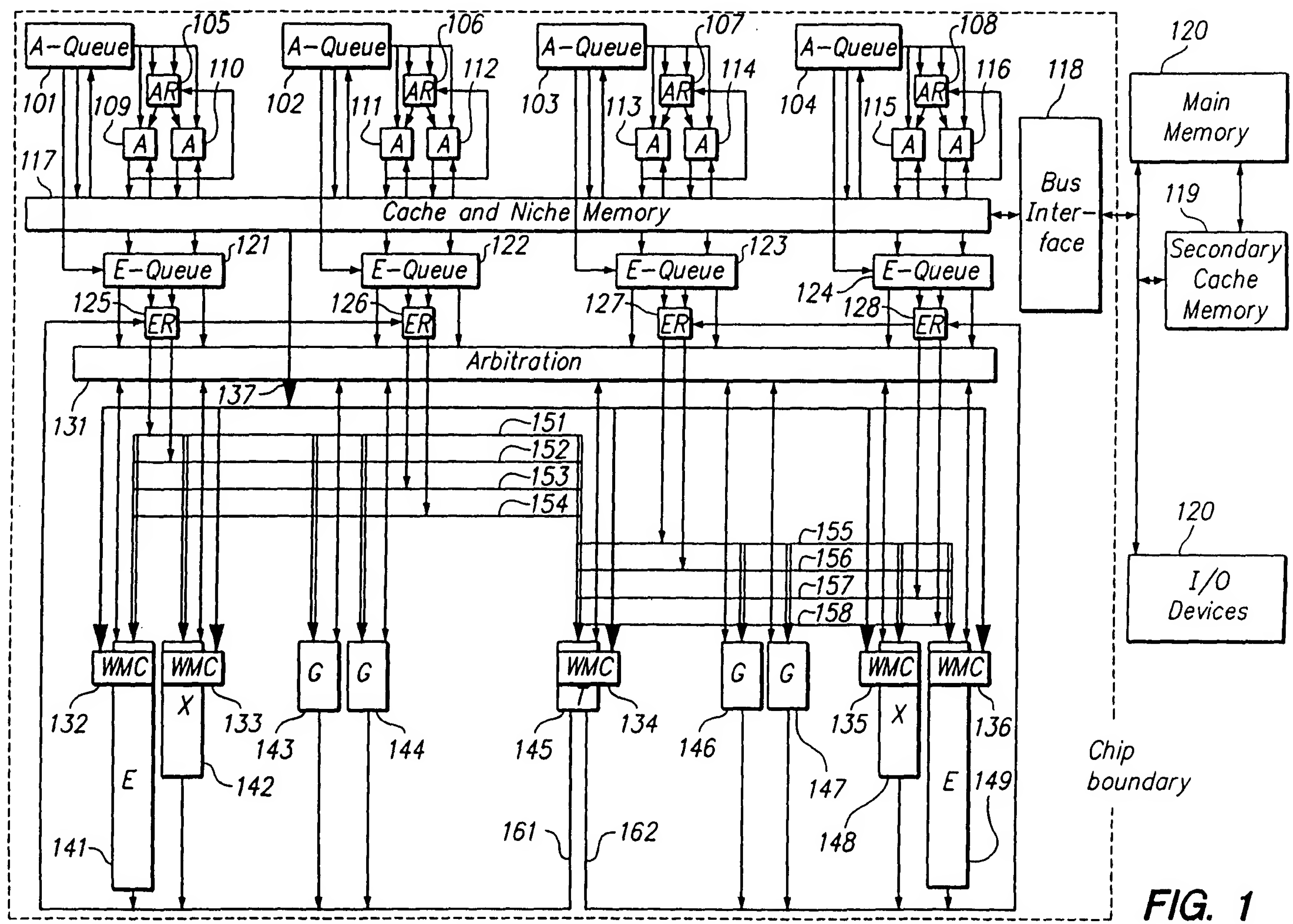

A-Queue
A-Queue
A-Queue
A-Queue
AR
AR
AR
AR
A
E-Queue
E-Queue
E-Queue
E-Queue
ER
Cache and Niche Memory
Arbitration
Bus Inter-face
Main Memory
Secondary Cache Memory
I/O Devices
WMC
G
X
E
T
Chip boundary
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
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161
162

FIG. 1

$\square\, rd_{128} = m[rc]_{(128*64/size)} * rb_{128}$

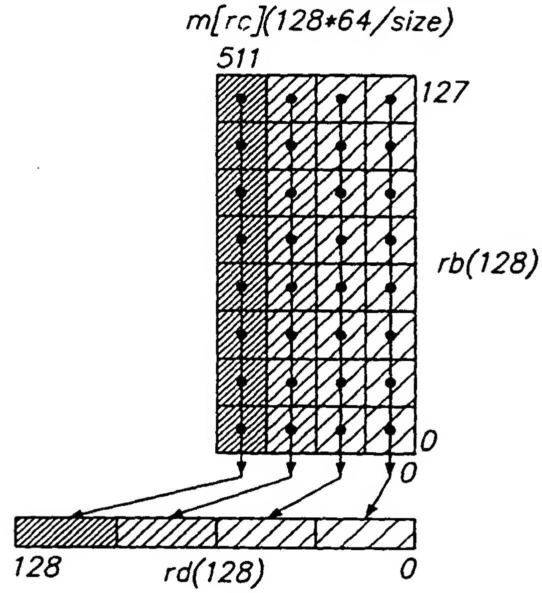


FIG. 2

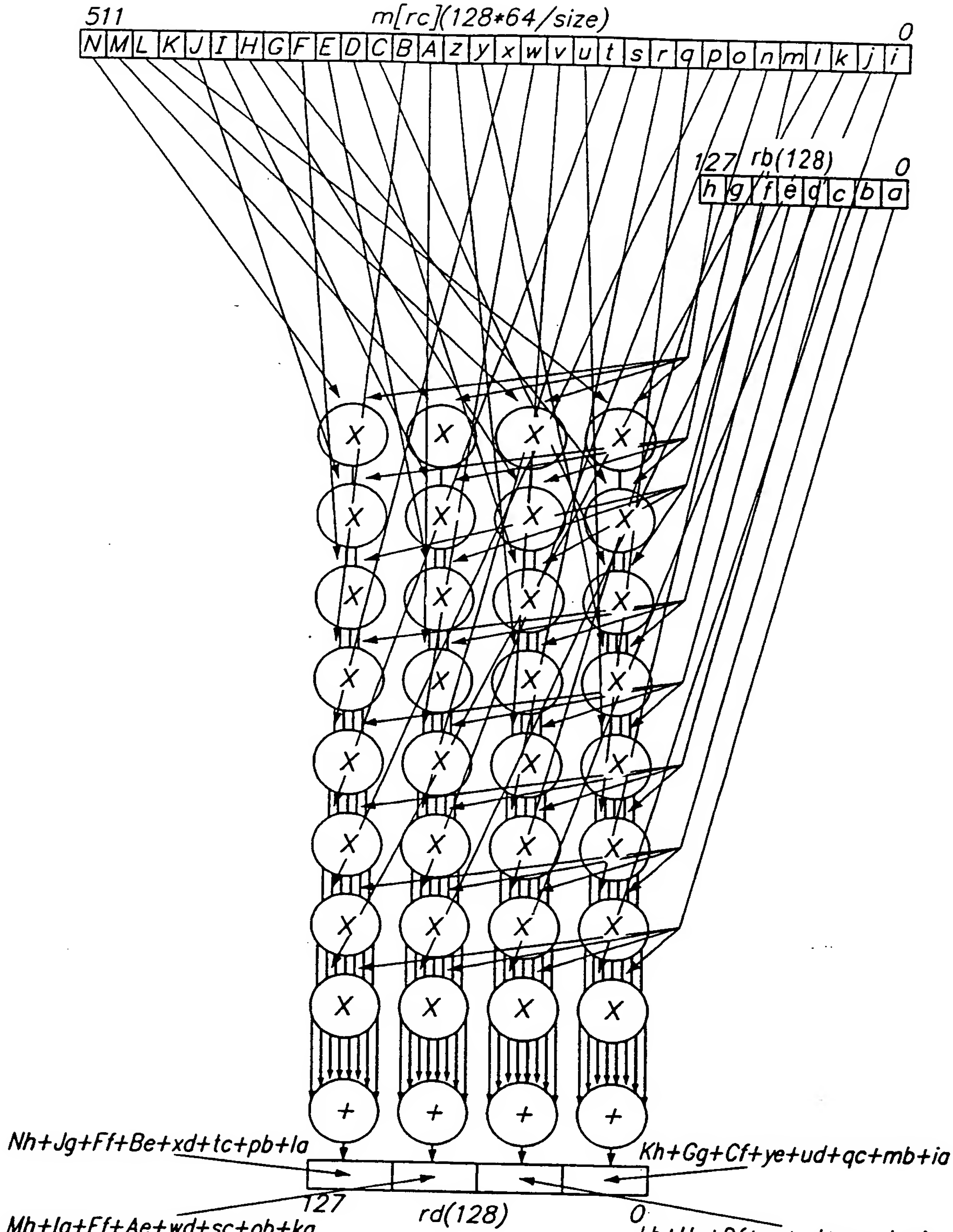
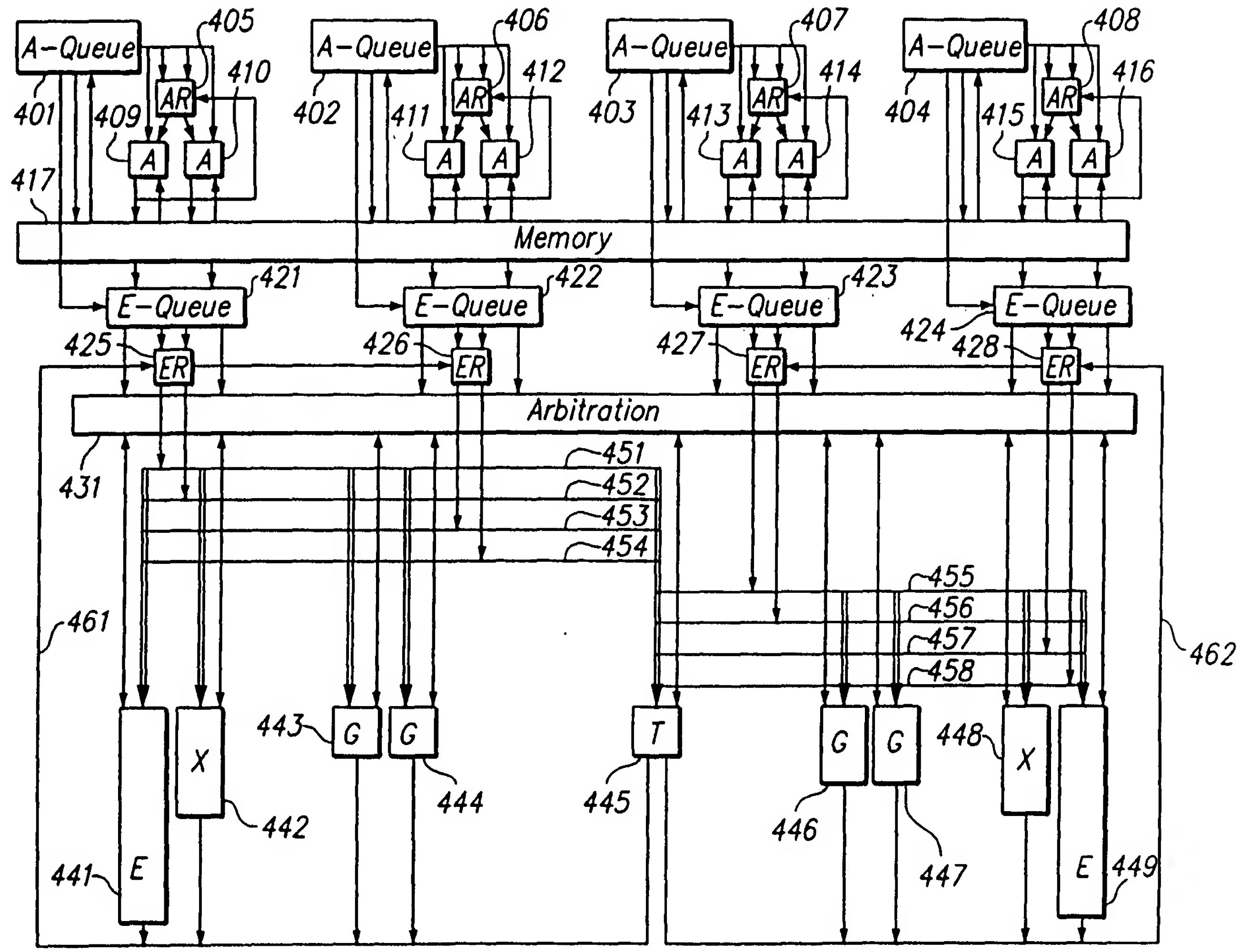

511
m[rc](128*64/size)
0
N M L K J I H G F E D C B A z y x w v u t s r q p o n m l k j i
127
rb(128)
0
h g f e d c b a
X
+
Nh+Jg+Ff+Be+xd+tc+pb+la
Kh+Gg+Cf+ye+ud+qc+mb+ia
127
rd(128)
0
Mh+Ig+Ef+Ae+wd+sc+ob+ka
Lh+Hg+Df+ze+vd+rc+nb+ja

FIG. 3


A-Queue
A-Queue
A-Queue
A-Queue
AR
AR
AR
AR
A
E-Queue
ER
Memory
Arbitration
E
X
G
T
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
421
422
423
424
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461
462

FIG. 4

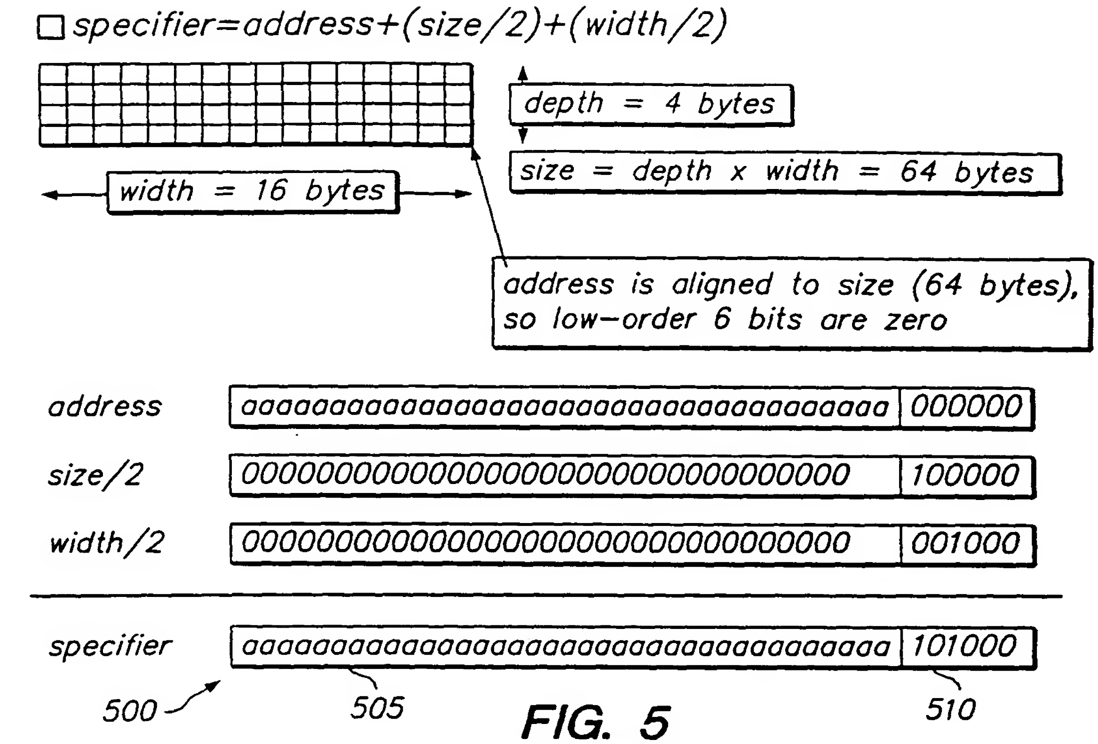

specifier=address+(size/2)+(width/2)
depth = 4 bytes
size = depth x width = 64 bytes
width = 16 bytes
address is aligned to size (64 bytes), so low-order 6 bits are zero
address
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
000000
size/2
00000000000000000000000000000000
100000
width/2
00000000000000000000000000000000
001000
specifier
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
101000
500
505
510

FIG. 5

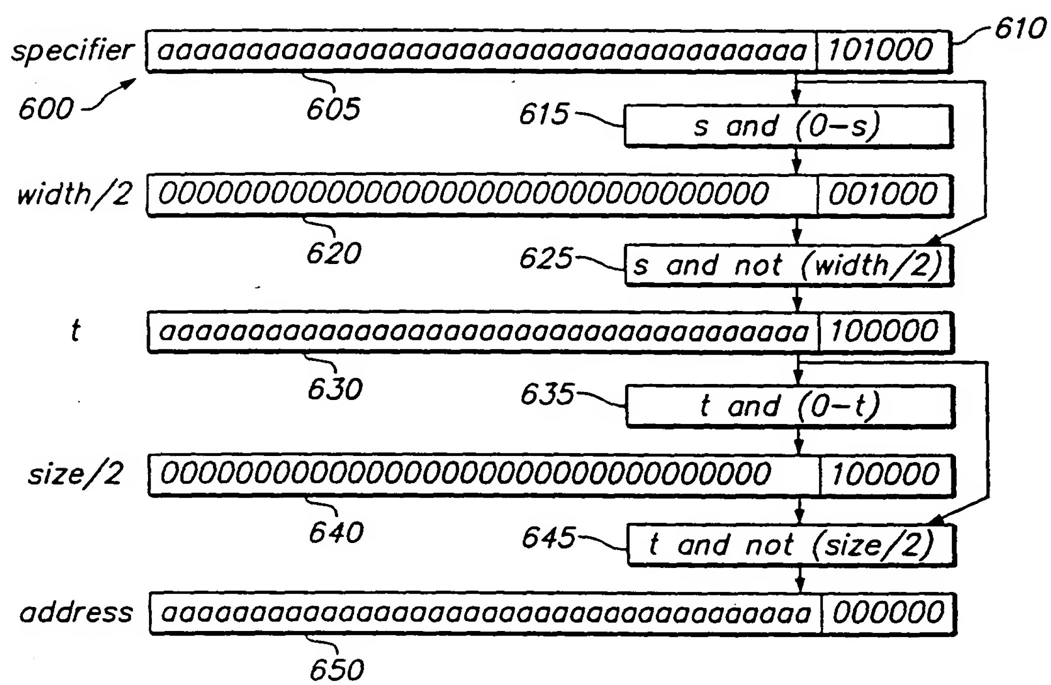

specifier
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
101000
610
600
605
615
s and (0-s)
width/2
00000000000000000000000000000000
001000
620
625
s and not (width/2)
t
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
100000
630
635
t and (0-t)
size/2
00000000000000000000000000000000
100000
640
645
t and not (size/2)
address
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
000000
650

FIG. 6

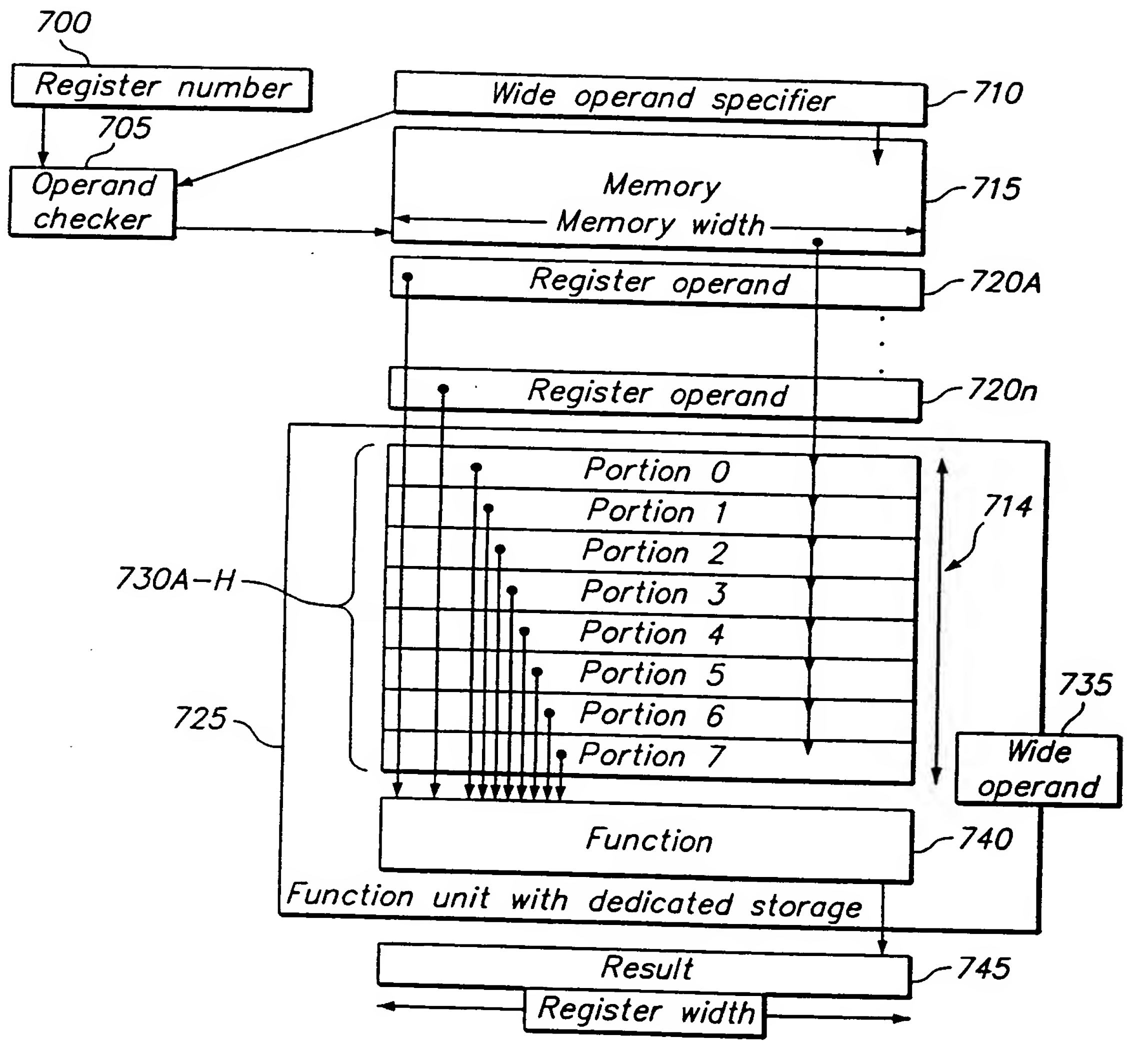

700
Register number
705
Operand checker
Wide operand specifier
710
Memory
Memory width
715
Register operand
720A
Register operand
720n
Portion 0
Portion 1
Portion 2
Portion 3
Portion 4
Portion 5
Portion 6
Portion 7
714
730A–H
725
735
Wide operand
Function
740
Function unit with dedicated storage
Result
745
Register width

FIG. 7

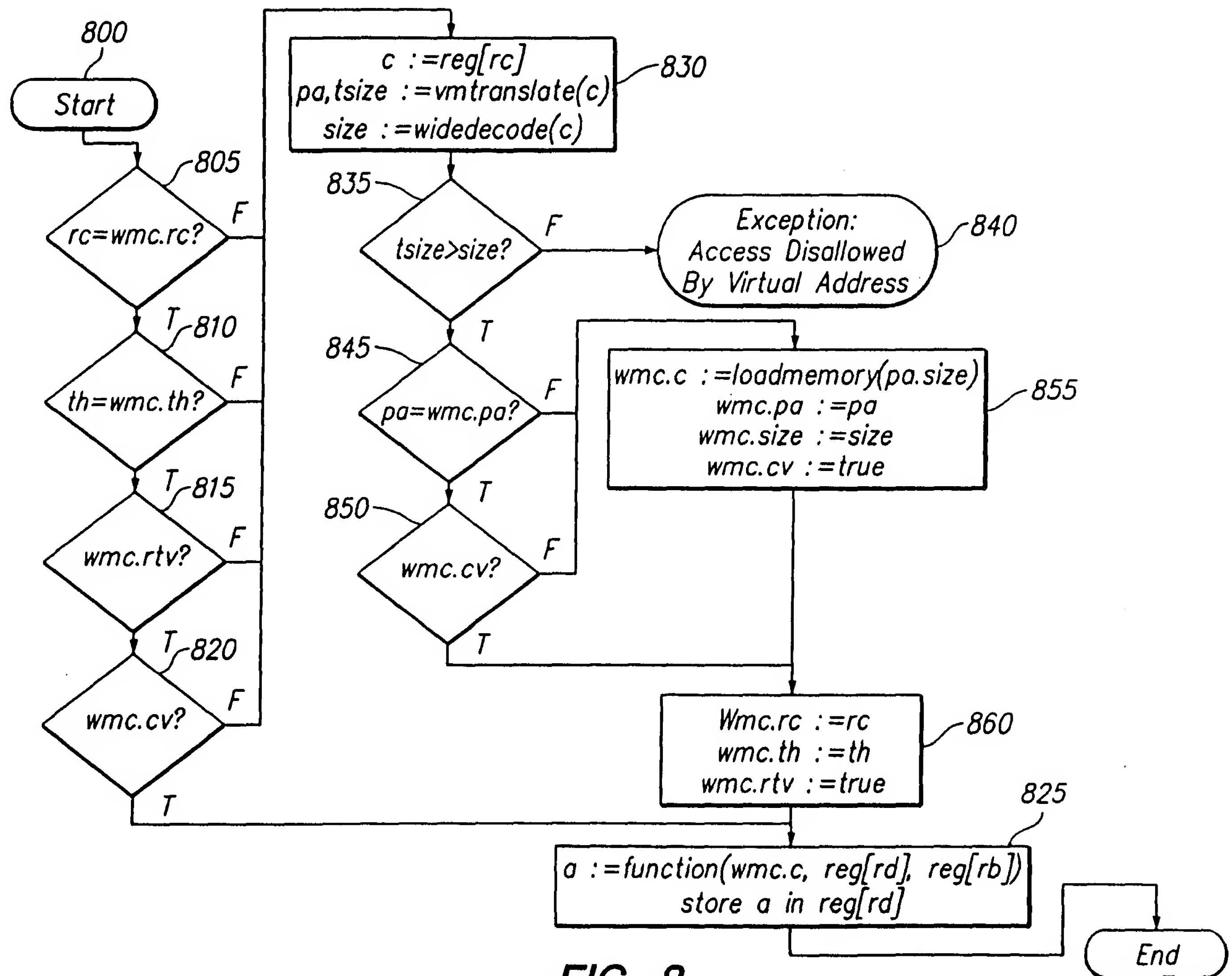

800
Start
805
rc=wmc.rc?
810
th=wmc.th?
815
wmc.rtv?
820
wmc.cv?
T
F
c :=reg[rc]
pa,tsize :=vmtranslate(c)
size :=widedecode(c)
830
835
tsize>size?
Exception:
Access Disallowed
By Virtual Address
840
845
pa=wmc.pa?
850
wmc.cv?
wmc.c :=loadmemory(pa.size)
wmc.pa :=pa
wmc.size :=size
wmc.cv :=true
855
Wmc.rc :=rc
wmc.th :=th
wmc.rtv :=true
860
825
a :=function(wmc.c, reg[rd], reg[rb])
store a in reg[rd]
End

FIG. 8

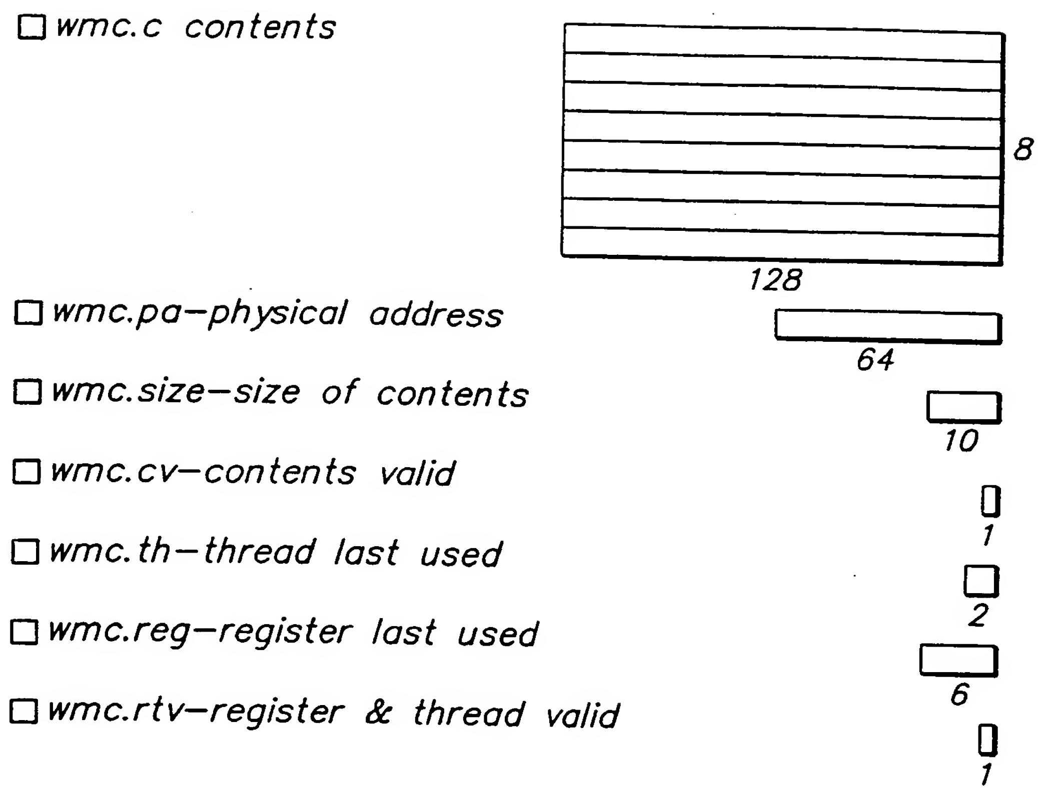

wmc.c contents
8
128
wmc.pa–physical address
64
wmc.size–size of contents
10
wmc.cv–contents valid
1
wmc.th–thread last used
2
wmc.reg–register last used
6
wmc.rtv–register & thread valid
1

FIG. 9

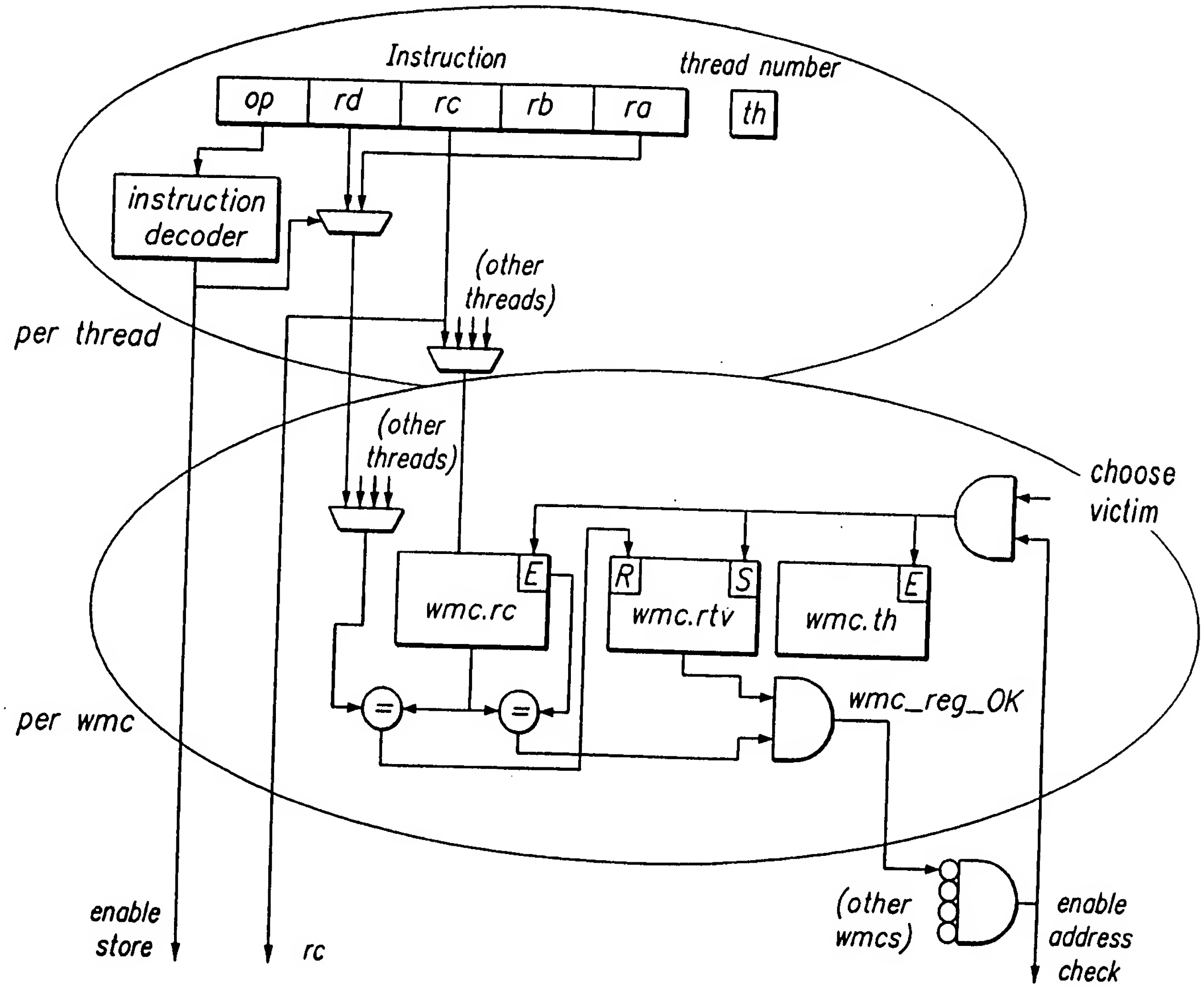

Instruction
op
rd
rc
rb
ra
thread number
th
instruction decoder
(other threads)
per thread
(other threads)
choose victim
E
wmc.rc
R
S
wmc.rtv
E
wmc.th
per wmc
=
=
wmc_reg_OK
(other wmcs)
enable store
rc
enable address check

FIG. 10

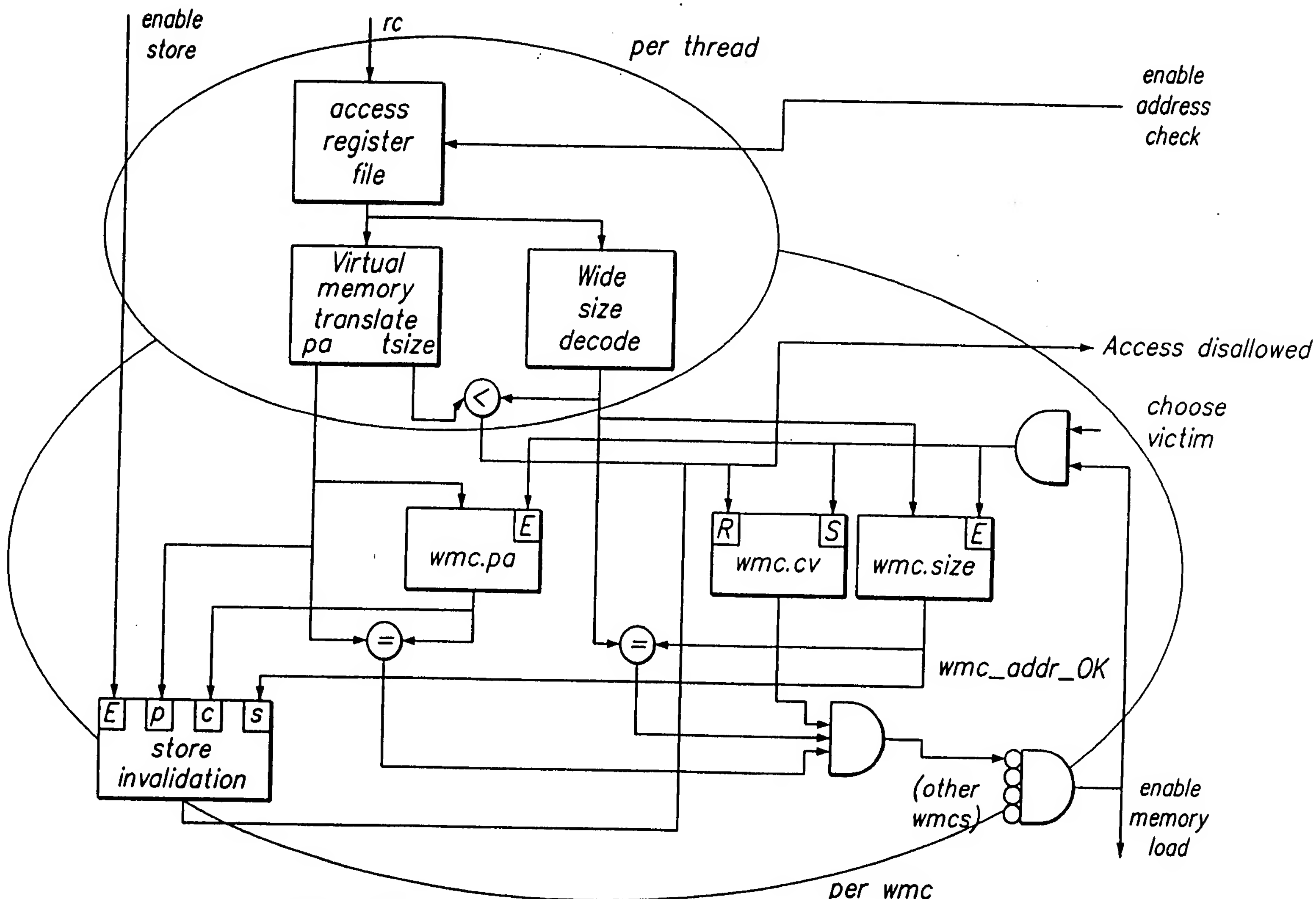

enable store
rc
per thread
enable address check
access register file
Virtual memory translate
pa
tsize
Wide size decode
Access disallowed
choose victim
wmc.pa
E
R
S
wmc.cv
wmc.size
E
wmc_addr_OK
E
p
c
s
store invalidation
(other wmcs)
enable memory load
per wmc

FIG. 11

210

Operation codes

W.SWITCH.B	Wide switch big-endian
W.SWITCH.L	Wide switch little-endian

Selection

class	op	order
Wide switch	W.SWITCH	B L

Format

W.op.order ra=rc,rd,rb

ra=woporder(rc,rd,rb)

31 24	23 18	17 12	11 6	5 0
W.op.order	rd	rc	rb	ra
8	6	6	6	6

FIG. 12A

1230

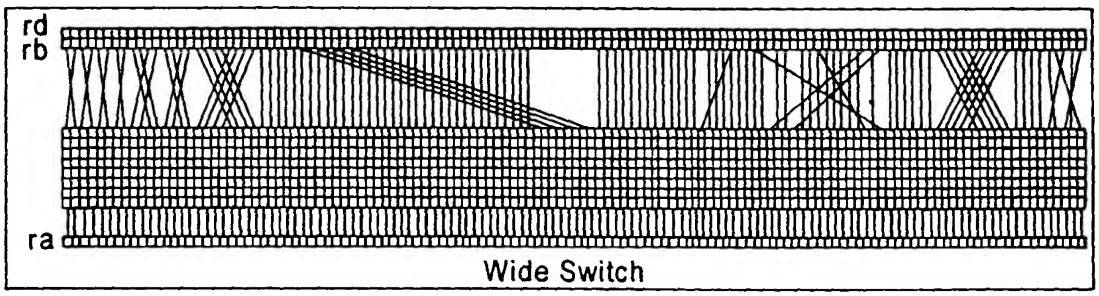


FIG. 12B

1250

Definition

```
defWideSwitch(op,rd,rc,rb,ra)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 64)
    b ← RegRead(rb, 128)
    if c1..0 ≠ 0 then
            raise AccessDisallowedByVirtual Address
    elseif c6..0 ≠0 then
            VirtAddr ← c and (c-1)
            W ← wsize ← (c and (0-c)) || 0^1
    else
            VirAddr ← c
            w ← wsize ← 128
    endif
    msize ← 8*wsize
    lwsize ← log(wsize)
    case op of
            W.SWITCH.B:
                order ← B
            W.SWITCH.L:
                order ← L
    endcase
    m ← LoadMemory(c, VirtAddr,msize,order)
    db ← d || b
    for i ← 0 to 127
            j ← 0|| i1wsize-1..0
            k ← m7•w+j || m6•w+j || m5•w+j || m4•w+j || m3•w+j || m2•w+j || mw+j || mj
            1 ← i7..1wsize || j1wsize-1..0
            ai ← db1
    endfor
    RegWrite(ra, 128, a)
enddef
```

FIG. 12C

1200

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 12D

1210

Operation codes

W.TRANSLATE.8.B	Wide translate bytes big-endian
W.TRANSLATE.16.B	Wide translate doublets bit-endian
W.TRANSLATE.32.B	Wide translate quadlets bit-endian
W.TRANSLATE.64.B	Wide translate octlets big-endian
W.TRANSLATE.8.L	Wide translate bytes little-endian
W.TRANSLATE.16.L	Wide translate doublets little-endian
W.TRANSLATE.32.L	Wide translate quadlets little-endian
W.TRANSLATE.64.L	Wide translate octlets little-endian

Selection

class	size	order
Wide translate	8 16 32 64	B L

Format

W.TRANSLATE.size.order rd=rc,rb

rd=wtranslatesizeorder(rc,rb)

31 24	34 18	17 12	11 6	5 2	1 0
W.TRANSLATE.order	rd	rc	rb	0	sz
6	6	6	6	4	2

sz ← log(size) = 3

FIG. 13A

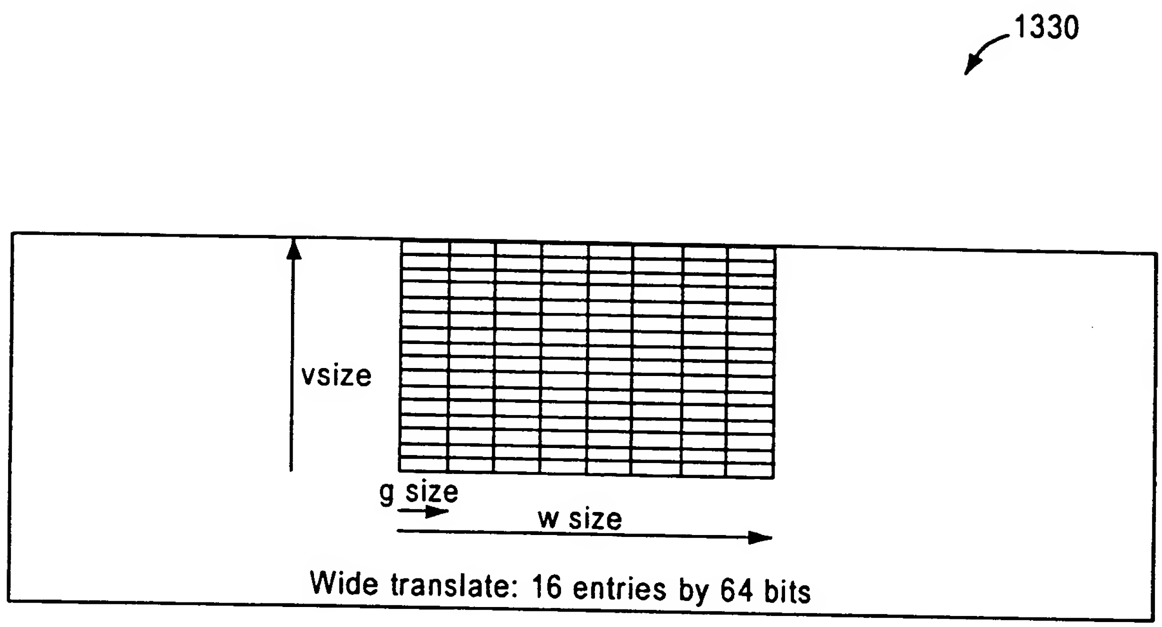


FIG. 13B

1350

Definition

```
def Wide Translate(op,gsize,rd,rc,rb)
      c ← RegRead(rc, 64)
      b ← RegRead(rb, 128)
      lgsize ← log(gsize)
      if c_{lgsize-4..0} ≠ 0 then
            raise AccessDisallowedByVirtual Address
      endif
      if c_{4..lgsize-3} ≠ 0 then
            wsize ← (c and (0-c)) || 0^3
            t ← c and (c-1)
      else
            wsize ← 128
            t ← c
      endif
      lwsize ← log(wsize)
if t_{lwsize+4..lwsize-2} ≠ 0 then
            msize ← (t and (0-t)) || 0^4
            VirtAddr ← t and (t-1)
      else
            msize ← 256*wsize
            VirtAddr ← t
      endif
      case op of
            W.TRANSLATE.B:
                  order ← B
            W.TRANSLATE.L:
                  order ← L
      endcase
      m ← LoadMemory(c,VirtAddr,msize,order)
      vsize ← msize/wsize
      lvsize ← log(vsize)
      for i ← 0 to 128-gsize by gsize
            j ← ((order=B)^lvsize)^(b_{lvsize-1+i..i}))*wsize+i_{lwsize-1..0}
            a_{gsize-1+i..i} ← m_{j+gsize-1..j}
      endfor
      RegWrite(rd, 128, a)
enddef
```

FIG. 13C

1380

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 13D

Operation codes

1410

W.MUL.MAT.8.B	Wide multiply matrix signed byte big-endian
W.MUL.MAT.8.L	Wide multiply matrix signed byte little-endian
W.MUL.MAT.16.B	Wide multiply matrix signed doublet big-endian
W.MUL.MAT.16.L	Wide multiply matrix signed doublet little-endian
W.MUL.MAT.32.B	Wide multiply matrix signed quadlet big-endian
W.MUL.MAT.32.L	Wide multiply matrix signed quadlet little-endian
W.MUL.MAT.C.8.B	Wide multiply matrix signed complex byte big-endian
W.MUL.MAT.C.8.L	Wide multiply matrix signed complex byte little-endian
W.MUL.MAT.C.16.B	Wide multiply matrix signed complex doublet big-endian
W.MUL.MAT.C.16.L	Wide multiply matrix signed complex doublet little-endian
W.MUL.MAT.M.8.B	Wide multiply matrix mixed-signed byte big-endian
W.MUL.MAT.M.8.L	Wide multiply matrix mixed-signed byte little-endian
W.MUL.MAT.M.16.B	Wide multiply matrix mixed-signed doublet big-endian
W.MUL.MAT.M.16.L	Wide multiply matrix mixed-signed doublet little-endian
W.MUL.MAT.M.32.B	Wide multiply matrix mixed-signed quadlet big-endian
W.MUL.MAT.M.32.L	Wide multiply matrix mixed-signed quadlet little-endian
W.MUL.MAT.P.8.B	Wide multiply matrix polynomial byte big-endian
W.MUL.MAT.P.8.L	Wide multiply matrix polynomial byte little-endian
W.MUL.MAT.P.16.B	Wide multtply matrix polynomial doublet big-endian
W.MUL.MAT.P.16.L	Wide multiply matrix polynomial doublet little-endian
W.MUL.MAT.P.32.B	Wide multiply matrix polynomial quadlet big-endian
W.MUL.MAT.P.32.L	Wide multiply matrix polynomial quadlet little-endian
W.MUL.MAT.U.8.B	Wide multiply matrix unsigned byte big-endian
W.MUL.MAT.U.8.L	Wide multiply matrix unsigned byte little-endian
W.MUL.MAT.U.16.B	Wide multiply matrix unsigned doublet big-endian
W.MUL.MAT.U.16.L	Wide multiply matrix unsigned doublet little-endian
W.MUL.MAT.U.32.B	Wide multiply matrix unsigned quadlet big-endian
W.MUL.MAT.U.32.L	Wide multiply matrix unsigned quadlet little-endian

Selection

class	op	type	size	order
multiply	W.MUL.MAT	NONE MUP	8 16 32	B L
		C	8 16	B L

Format

W.op.size.order rd=rc,rb

rd=wopsizeorder(rc,rb)

31 24	23 18	17 12	11 6	5 2	1 0
W.MINOR.order	rd	rc	rb	W.op	sz
8	6	6	6	4	2

sz ← log(size) - 3

FIG. 14A

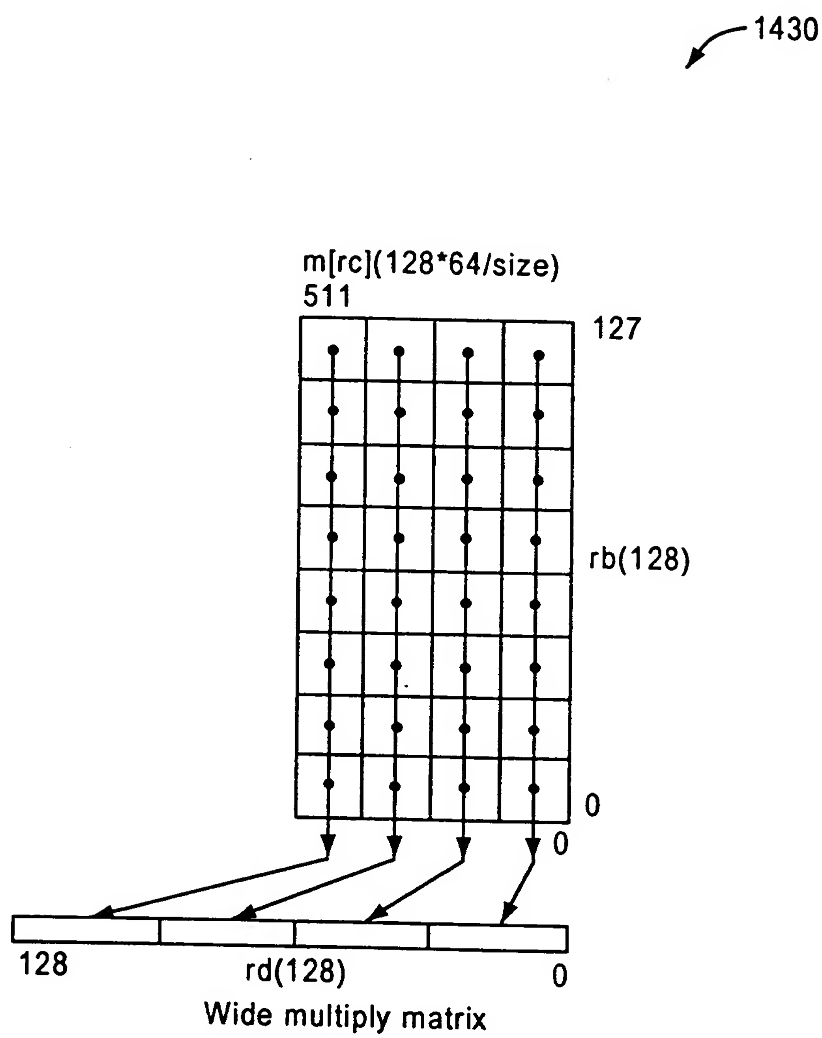
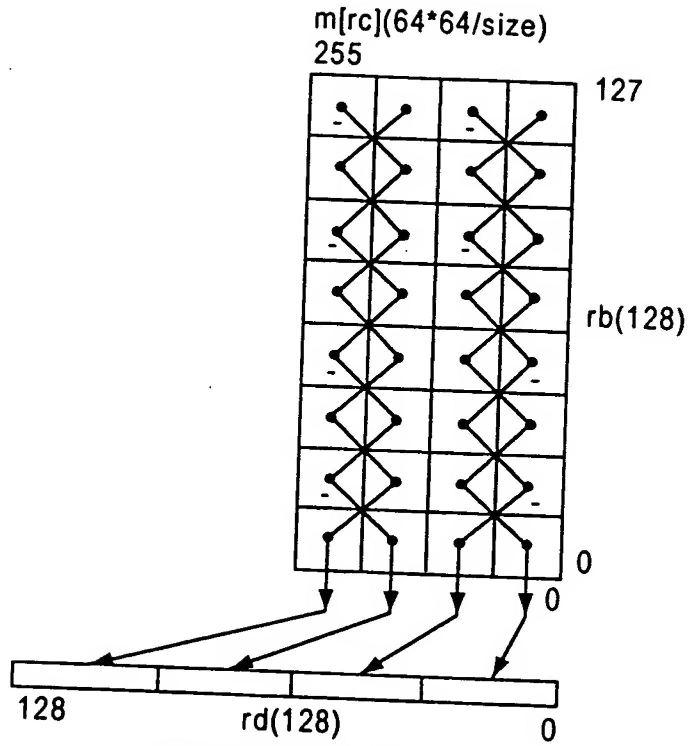

1430
m[rc](128*64/size)
511
127
rb(128)
0
0
128
rd(128)
0
Wide multiply matrix

FIG. 14B

1460



Wide multiply matrix complex

FIG. 14C

1480

<u>Definition</u>

```
def mul(size,h,vs,v,i,ws,j)as
    mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) *((ws&w_{size-1+j})^{h-size}|| w_{size-1+j..j} )
enddef

def c ← PolyMultiply(size,a,b) as
    p[0] ← 0^{2*size}
    for k ← 0 to size-1
        p[k+1] ← p[k] ^ a_k ? (0^{size-k}|| b || 0^k ) : 0^{2*size}
    endfor
    c ← p[size]
enddef

def WideMultiplyMatrix(major,op,gsize,rd,rc,rb)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 64)
    b ← RegRead(rb,128)
    lgsize ← log(gsize)
    if c_{lgsize-4..0} ≠ 0 then
        raise AccessDisallowedByVirtualAddress
    endif
    if c_{2..lgsize-3} ≠ 0 then
        wsize ← (c and (0-c)) || 0^4
        t ← c and (c-1)
    else
        wsize ← 64
        t ← a
    endif
    lwsize ← log(wsize)
    if t_{lwsize+6-lgsize..lwsize-3} ≠ 0 then
        msize ← (t and (0-t)) || 0^4
        VirtAddr ← t and (t-1)
    else
        msize ← 128*wsize/gsize
        VirtAddr ← t
    endif
    case major of
        W.MINOR.B:
            order ← B
        W.MINOR.L:
            order ← L
    endcase
```

FIG. 14D-1

1480

```
case op of
      M.MUL.MAT.U.8, W.MUL.MAT.U.16, W.MUL.MAT.U.32,
      W.MUL.MAT.U.64:
            ms ← bs ← 0
      W.MUL.MAT.M.8, W.MUL.MAT.M.16, W.MUL.MAT.M.32,
      W.MUL.MAT.M.64
            ms ← 0
            bs ← 1
      W.MUL.MAT.8, W.MUL.MAT.16, W.MUL.MAT.32,
      W.MUL.MAT.64, W.MUL.MAT.C.8, W.MUL.MAT.C.16,
      W.MUL.MAT.C.32, W.MUL.MAT.C.64:
            ms ← bs ← 1
      W.MUL.MAT.P.8, W.MUL.MAT.P.16, W.MUL.MAT.P.32,
      W.MUL.MAT.P.64:
endcase
m ← LoadMemory(c,VirtAddr,msize,order)
h ← 2*gsize

for i ← 0 to wsize-gsize by gsize
      q[0] ← 0^(2*gsize)
      for j ← 0 to vsize-gsize by gsize
            case op of
                  W.MUL.MAT.P.8, W.MUL.MAT.P.16,
                  W.MUL.MAT.P.32, W.MUL.MAT.P.64:
                        k ← i+wsize*j_(8..lgsize)
                        q[j+gsize] ← q[j] ^ PolyMultiply(gsize,m_(k+gsize-1..k),
                        b_(j+gsize-1..j))
                  W.MUL.MAT.C.8, W.MUL.MAT.C.16, W.MUL.MAT.C.32,
                  W.MUL.MAT.C.64:
                        if (~i) & gsize = 0 then
                              k ← i-(j&gsize)+wsize*j_(8..lgsize+1)
                              q[j+gsize] ← q[i] + mul(gsize,h,ms,m,k,bs,b,j)
                        else
                              k ← i+gsize+wsize*j_(8..lgsize+1)
                              q[i+gsize] ← q[i] = mul(gsize,h,ms,m,k,bs,b,j)
                        endif
```

FIG. 14D-2

1480

```
            W.MUL.MAT.8, W.MUL.MAT.16, W.MUL.MAT.32,
            W.MUL.MAT.64, W.MUL.MAT.M.8, W.MUL.MAT.M.16,
            W.MUL.MAT.M.32, W.MUL.MAT.M.64, W.MUL.MAT.U.8,
            W.MUL.MAT.U.16, W.MUL.MAT.U.32, W.MUL.MAT.U.64
                q[i+gsize] ← q[i] + mul(gsize,h,ms,m,i+wsize*
                j8..lgsize,bs,b,j)
        endfor
        a2*gsize-1+2*i..2*i ← q[vsize]
    endfor
    a127..2*wsize ← 0
    RegWrite(rd, 128, a)
enddef
```

FIG. 14D-3

1490

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 14E

1510

Operation codes

W.MUL.MAT.X.B	Wide multiply matrix extract big-endian
W.MUL.MAT.X.L	Wide multiply matrix extract little-indian

Selection

class	op	order
Multiply matrix extract	W.MUL.MAT.X	B L

Format

W.op.order ra=rc,rd,rb

ra=wop(rc,rd,rb)

31 24	23 18	17 12	11 6	5 0
W.op.order	rd	rc	rb	ra
8	6	6	6	6

FIG. 15A

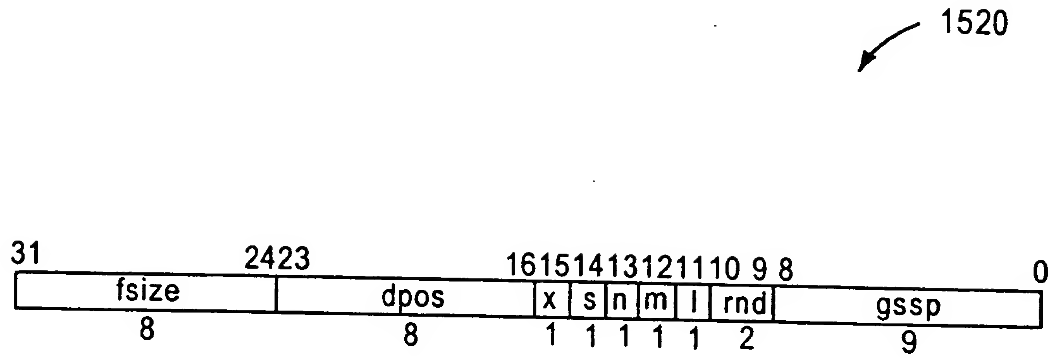
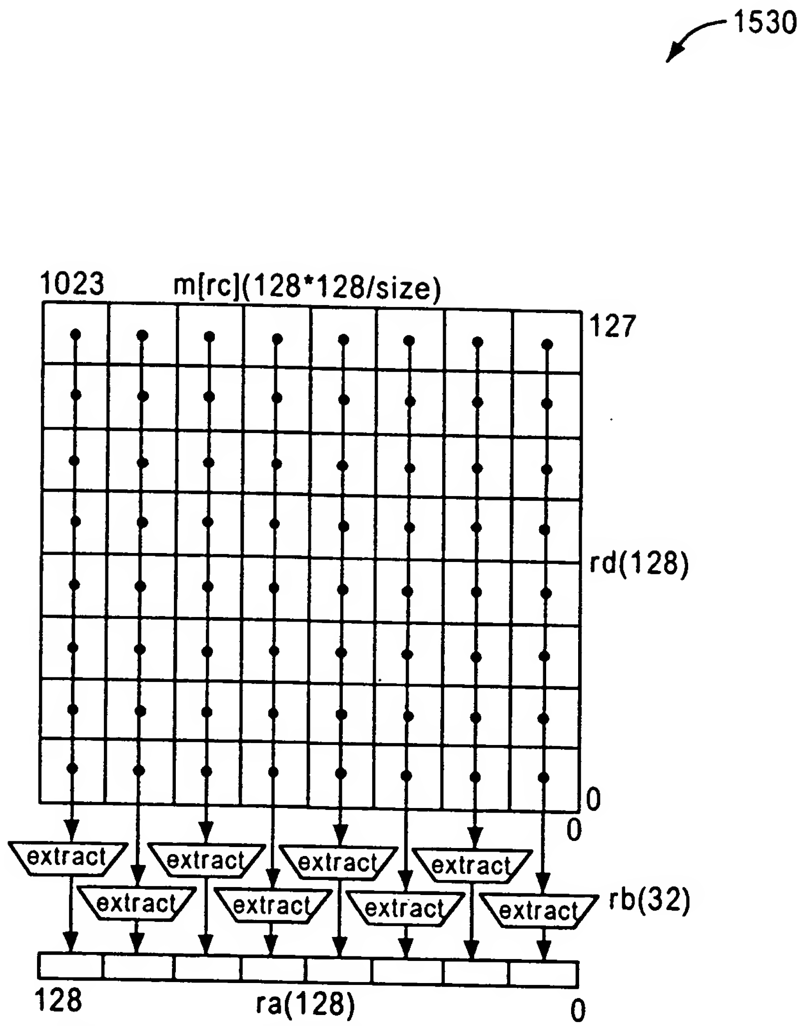
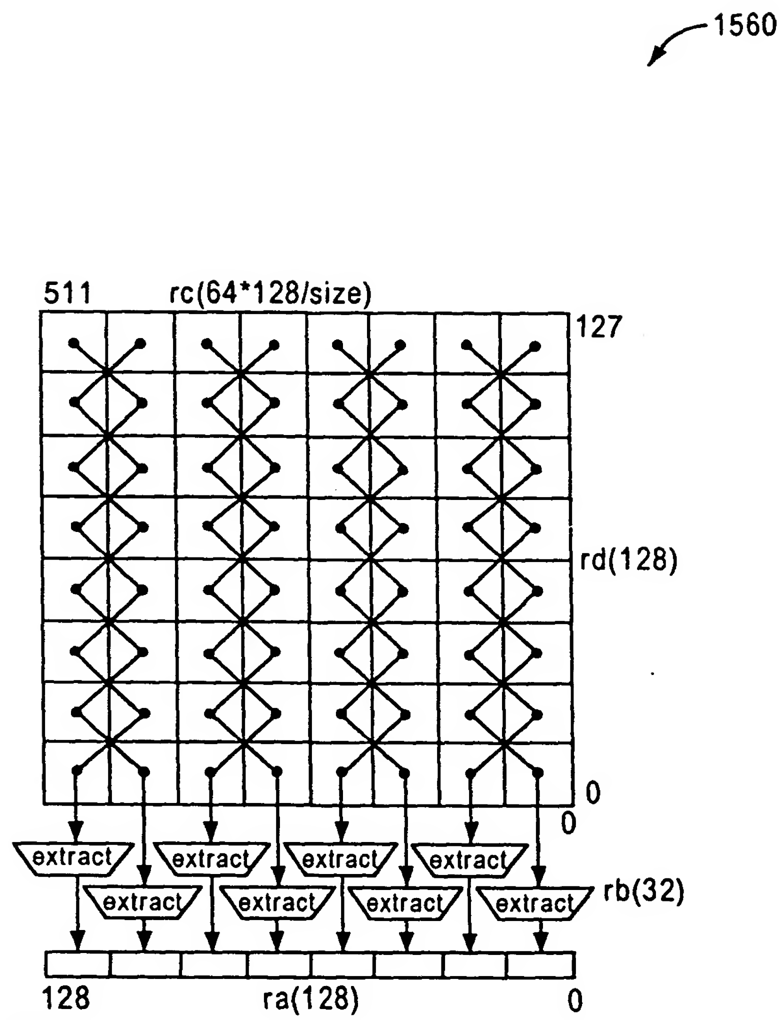

1520
31
2423
16151413121110 9 8
0
fsize
dpos
x
s
n
m
l
rnd
gssp
8
8
1
1
1
1
1
2
9

FIG. 15B



Wide multiply matrix extract doublets

FIG. 15C



Wide multiply matrix extract complex doublets

FIG. 15D

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
    mul ← ((vs&v_size-1+i)^h-size || v_size-1+i..i) * ((ws&w_size-1+j)^h-size || w_size-1+j..j)
enddef
```

1580

```
def WideMultiplyMatrixExtract(op,ra,rb,rc,rd)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 64)
    b ← RegRead(rb, 128)
    case b8..0 of
        0..255:
            sgsize ← 128
        256..383:
            sgsize ← 64
        384..447:
            sgsize ← 32
        448..479:
            sgsize ← 16
        480..495:
            sgsize ← 8
        496..503:
            sgsize ← 4
        504..507:
            sgsize ← 2
        508..511:
            sgsize ← 1
    endcase
    l ← b11
    m ← b12
    n ← b13
    signed ← b14
    if c3..0 ≠ 0 then
        wsize ← (c and (0-c)) || 0^4
        t ← c and (c-1)
    else
        wsize ← 128
        t ← c
    endif
    if sgsize < 8 then
        gsize ← 8
    elseif sgsize > wsize/2 then
        gsize ← wsize/2
    else
```

FIG. 15E-1

1580

```
     gsize ← sgsize
endif
lgsize ← log(gsize
lwsize ← log(wsize)
if t_lwsize+6-n-lgsize..lwsize-3 ≠ 0 then
     msize ← (t and (0-t)) || 0^4
     VirtAddr ← t and (t-1)
else
     msize ← 64*(2-n)*wsize/gsize
     VirtAddr ← t
endif
vsize ← (1+n)*msize*gsize/wsize
mm ← LoadMemory(c,VirtAddr,msize,order)
lmsize ← log(msize)
if (VirtAddr_lmsize-4..0 ≠ 0 then
     raise AccessDisallowedByVirtualAddress
endif
case op of
     W.MUL.MAT.X.B:
          order ← B
     W.MUL.MAT.X.L:
          order ← L
endcase
ms ← signed
ds ← signed ^ m
as ← signed or m
spos ← (b_8..0) and (2*gsize-1)
dpos ← (0 || b_23..16) and (gsize-1)
r ← spos
sfsize ← (0 || b_31..24) and (gsize-1)
tfsize ← (sfsize = 0) or ((sfsize+dpos) > gsize) ? gsize-dpos : sfsize
fsize ← (tfsize + spos > h) ? h - spos : tfsize
if (b_10..9 = Z) & ~signed then
     rnd ← F
else
     rnd ← b_10..9
endif
```

FIG. 15E-2

1580

```
for i ← 0 to wsize-gsize by gsize
    q[0] ← 0^(2*gsize+7-lgsize)
    for j ← 0 to vsize-gsize by gsize
        if n then
            if (~) & j & gsize = 0 then
                k ← i-(j&gsize)+wsize*j_(8..lgsize+1)
                q[i+gsize] ← q[i] + mul(gsize,h,ms,mm,k,ds,d,j)
            else
                k ← i+gsize+wsize*j_(8..lgsize+1)
                q[i+gsize] ← q[i] - mul(gsize,h,ms,mm,k,ds,d,j)
            endif
        else
            q[i+gsize] ← q[i] = mul(gsize,h,ms,mm,i+j*wsize/gsize,ds,d,j)
        endif
    endfor
    p ← q[128]
    case rnd of
        none, N:
            s ← 0^(h-r) || ~p_r || p_r^(r-1)
        Z:
            s ← 0^(h-r) || p_(h-1)^r
        F:
            s ← 0^h
        C:
            s ← 0^(h-r) || 1^r
    endcase
    v ← ((ds & p_(h-1)) || p) + (0 || s)

        if (v_(h..r+fsize) = (as & v_(r+fsize-1))^(h+1-r-fsize)) or not I then
            w ← (as & v_(r+fsize-1))^(gsize-fsize-dpos) || v_(fsize-1+r..r) || 0^dpos
        else
            w ← (s ? (v_h || ~v_h^(gsize-dpos-1)) : 1^(gsize-dpos)) || 0^dpos
        endif
        a_(size-1+i..i) ← w
    endfor
    a_(127..wsize) ← 0
    RegWrite(ra, 128, a)
enddef
```

FIG. 15E-3

1570

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 15F

1610

Operation codes

W.MUL.MAT.X.I.8.B	Wide multiply matrix extract immediate signed byte big-endian
W.MUL.MAT.X.I.8.L	Wide multiply matrix extract immediate signed byte little-endian
W.MUL.MAT.X.I.16.B	Wide multiply matrix extract immediate signed doublet big-endian
W.MUL.MAT.X.I.16.L	Wide multiply matrix extract immediate signed doublet little-endian
W.MUL.MAT.X.I.32.B	Wide multiply matrix extract immediate signed quadlet big-endian
W.MUL.MAT.X.I.32.L	Wide multiply matrix extract immediate signed quadlet little-endian
W.MUL.MAT.X.I.64.B	Wide multiply matrix extract immediate signed octlets big-endian
W.MUL.MAT.X.I.64.L	Wide multiply matrix extract immediate signed octlets little-endian
W.MUL.MAT.X.I.C.8.B	Wide multiply matrix extract immediate complex bytes big-endian
W.MUL.MAT.X.I.C.8.L	Wide multiply matrix extract immediate complex bytes little-endian
W.MUL.MAT.X.I.C.16.B	Wide multiply matrix extract immediate complex doublets big-endian
W.MUL.MAT.X.I.C.16.L	Wide multiply matrix extract immediate complex doublets little-endian
W.MUL.MAT.X.I.C.32.B	Wide multiply matrix extract immediate complex quadlets big-endian
W.MUL.MAT.X.I.C.32.L	Wide multiply matrix extract immediate complex quadlets little-endian

Selection

class	op	type	size	order
wide multiply extract immediate	W.MUL.MAT.X.I	NONE	8 16 32 64	L B
		C	8 16 32	L B

Format

W.op.tsize.order rd=rc,rb, i

rd=woptsizeorder(rc,rb,i)

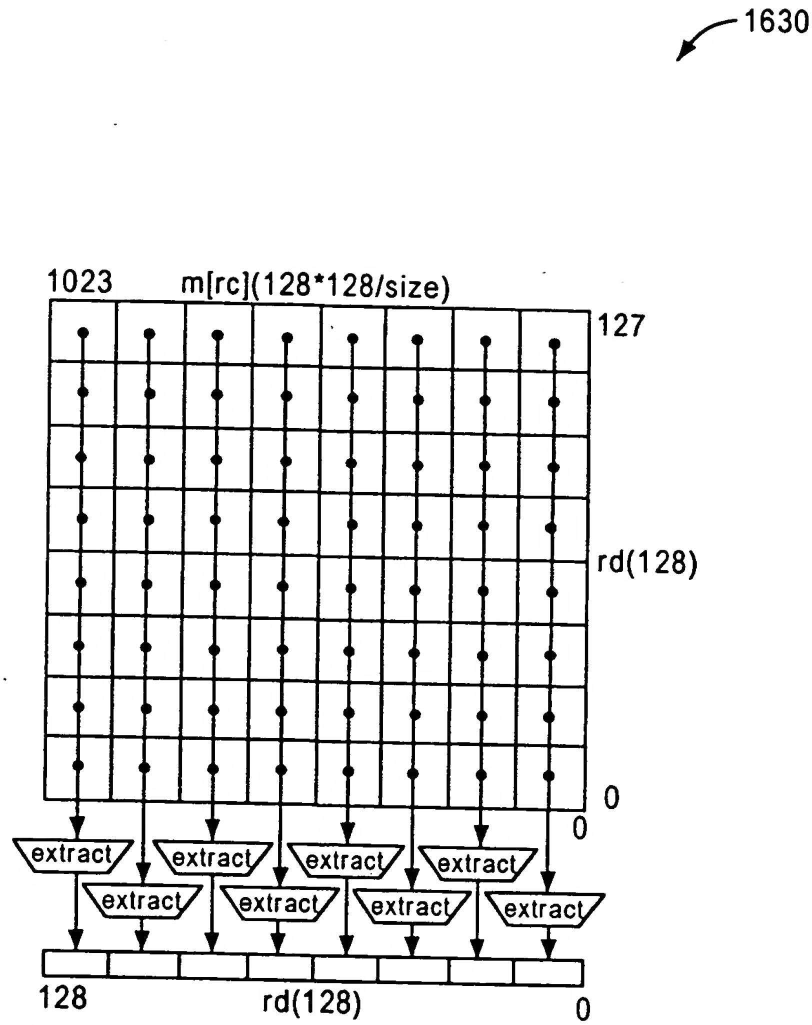
31 24	23 18	17 12	11 6	5	4 3	2 0
W.op.order	rd	rc	rb	t	sz	sh
8	6	6	6	1	2	3

sz ← log(size) - 3

assert size+3 ≥ i ≥ size-4

sh ← i - size

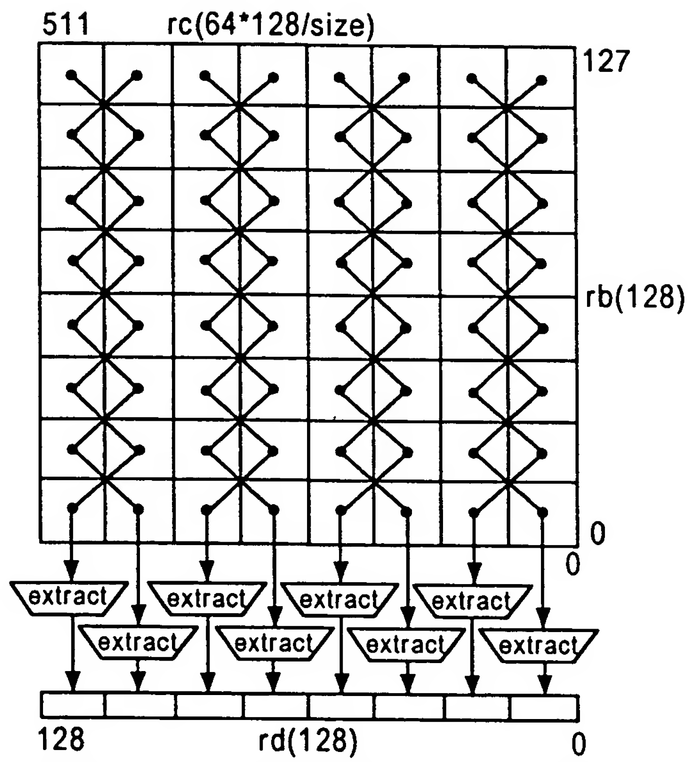
FIG. 16A



Wide multiply matrix extract immediate doublets

FIG. 16B

1660



Wide multiply matrix extract immediate complex doublets

FIG. 16C

1680

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
     mul ←((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def WideMultiplyMatrixExtractimmediate(op,type,gsize,rd,rc,rb,sh)
     c ← RegRead(rc, 64)
     b ← RegRead(rb, 128)
     lgsize ← log(gsize)
     case type of
          NONE:
               if c_{lgsize-4..0} ≠ 0 then
                    raise AccessDisallowedBy VirtualAddress
               endif
               if c_{3..lgsize-3} ≠ 0 then
                    wsize ← (c and (0-c)) || 0^4
                    t ← c and (c-1)
               else
                    wsize ← 128
                    t ← c
               endif
               lwsize ← log(wsize)
               if t_{lwsize+6-lgsize..lwsize-3} ≠ 0 then
                    msize ← (t and (0-t)) || 0^4
                    VirtAddr ← t and (t-1)
               else
                    msize ← 128*wsize/gsize
                    VirtAddr ← t
          C:
               if c_{lgsize-4..0} ≠ 0 then
                    raise AccessDisallowedByVirtualAddress
               endif
               if c_{3..lgsize-3} ≠ 0 then
                    wsize ← (c and (0-c)) || 0^4
                    t ← c and (c-1)
               else
                    wsize ← 128
                    t ← c
               endif
               lwsize ← log(wsize)
               if t_{lwsize+5-lgsize..lwsize-3} ≠ 0 then
                    msize ← (t and (0-t)) || 0^4
```

FIG. 16D-1

1680

```
                    VirtAddr ← t and (t-1)
               else
                    msize ← 64*wsize/gsize
                    VirtAddr ← t
               endif
               vsize ← 2*msize*gsize/wsize
     endcase
     case of of
          W.MUL.MAT.X.I.B:
               order ← B
          W.MUL.MAT.X.I.L:
               order ← L
     endcase
     as ← ms ← bs ← 1
     m ← LoadMemory(c,VirtAddr,msize,order)
     h ← (2*gsize) + 7 - lgsize-(ms and bs)
     r ← gsize + (sh_2^5||sh)
     for ← 0 to wsize-gsize by gsize
          q[0] ← 0^(2*gsize+7-lgsize)
          for j ← 0 to vsize-gsize by gsize
               case type of
                    NONE:
                         q[j+gsize] ← q[i] + mul(gsize,h,ms,m,i+wsize*
                          j_8..lgsize,bs,b,j )
                    C:
                         if (~i) & j & gsize = 0 then
                              k ← i-(j&gsize)+wsize*j_8..lgsize+1
                              q[j+gsize] ← q[i] + mul(gsize,h,ms,m,k,bs,b,j)
                         else
                              k ← i+gsize+wsize*j_8..lgsize+1
                              q[j+gsize] ← q[j] - mul(gsize,h,ms,m,k,bs,b,j)
                         endif
               endcase
          endfor
          p ← q[vsize]
          s ← 0^(h-r) || ~p_r || p_r^(r-1)
          v ← ((as & p_h-1)||p) + (0||s)
          if (v_h..r+gsize = (as & v_r+gsize-1)^(h+1-r-gsize) then
               a_gsize-1+i..i ← v_gsize-1+r..r
          else
               a_gsize-1+i..i ← as ? (v_h||~v_h^(gsize-1) ) : 1gsize
          endif
     endfor
     a_127..wsize ← 0
     RegWrite(rd, 128, a)
enddef
```

FIG. 16D-2

1690

<u>Exceptions</u>

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 16E

1710

Operation codes

W.MUL.MAT.C.F.16.B	Wide multiply matrix complex floating-point half big-endian
W.MUL.MAT.C.F.16.L	Wide multiply matrix complex floating-point little-endian
W.MUL.MAT.C.F.32.B	Wide multiply matrix complex floating-point single big-endian
W.MUL.MAT.C.F.32.L	Wide multiply matrix complex floating-point single little-endian
W.MUL.MAT.F.16.B	Wide multiply matrix floating-point half big-endian
W.MUL.MAT.F.16.L	Wide multiply matrix floating-point half little-endian
W.MUL.MAT.F.32.B	Wide multiply matrix floating-point single big-endian
W.MUL.MAT.F.32.L	Wide multiply matrix floating-point single little-endian
W.MUL.MAT.F.64.B	Wide multiply matrix floating-point double big-endian
W.MUL.MAT.F.64.L	Wide multiply matrix floating-point double little-endian

Selection

class	op	type	prec	order
wide multiply matrix	W.MUL.MAT	F	16 32 64	L B
		C.F	16 32	L B

Format

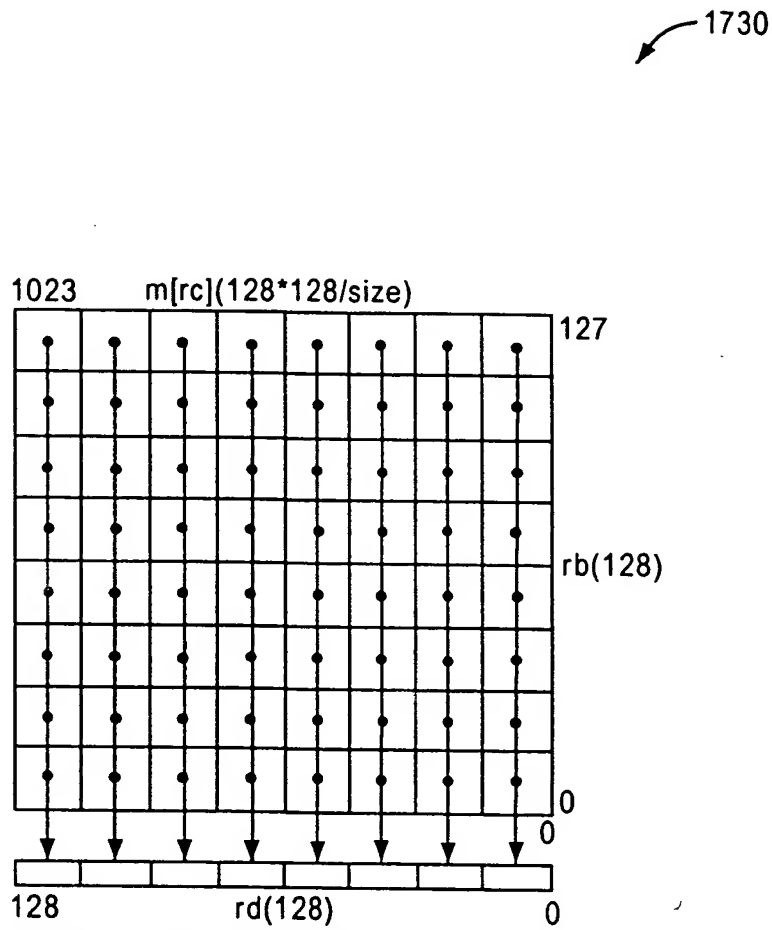
W.op.prec.order rd=rc,rb

rd=wopprecorder(rc,rb)

31 24	23 18	17 12	11 6	5 2	1 0
W.MINOR.order	rd	rc	rb	W.op	pr
8	6	6	6	4	2

Pr ← log(prec) - 3

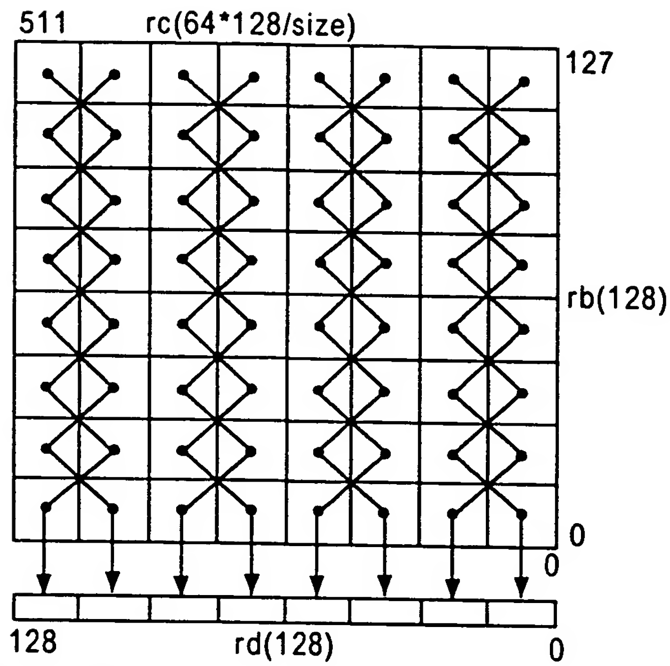
FIG. 17A



Wide multiply matrix floating-point half

FIG. 17B

1760



Wide multiply matrix complex floating-point half

FIG. 17C

1780

<u>Definition</u>

```
def mul(size,v,i,w,j) as
    mul ← fmul(F(size,v_{size-1+i..i}),F(size,w_{size-1+j..j} ))
enddef

def WideMultiplyMatrixFloatingPoint(major,op,gsize,rd,rc,rb)
    c ← RegRead(rc, 64)
    b ← RegRead(rb, 128)
    lgsize ← log(gsize)
    switch op of
        W.MUL.MAT.F.16, W.MUL.MAT.F.32, W.MUL.MAT.F.64:
            if c_{lgsize-4..0} ≠ 0 then
                raise AccessDisallowedByVirtualAddress
            endif
            if c_{3..lgsize-3} ≠ 0 then
                wsize ← (c and (0-c)) || 0^4
                t ← c and (c-1)
            else
                wsize ← 128
                t ← c
            endif
            lwsize ← log(wsize)
            if t_{lwsize+6-lgsize..lwsize-3} ≠ 0 then
                msize ← (t and (0-t)) || 0^4
                VirtAddr ← t and (t-1)
            else
                msize ← 128*wsize/gsize
                VirtAddr ← t
            endif
            vsize ← msize*gsize/wsize
        W.MUL.MAT.C.F.16, W.MUL.MAT.C.F.32, W.MUL.MAT.C.F.64:
            if c_{lgsize-4..0} ≠ 0 then
                raise AccessDisallowedByVirtualAddress
            endif
            if c_{3..lgsize-3} ≠ 0 then
                wsize ← (c and (0-c)) || 0^4
                t ← c and (c-1)
            else
                wsize ← 128
                t ← c
            endif
            lwsize ← log(wsize)
            if t_{lwsize+5-lgsize..lwsize-3} ≠ 0 then
```

FIG. 17D-1

1780

```
                msize ← (t and (0-t)) || 0^4
                VirtAddr ← t and (t-1)
            else
                msize ← 64*wsize/gsize
                VirtAddr ← t
            endif
            vsize ← 2*msize*gsize/wsize
    endcase
    case major of
        M.MINOR.B:
            order ← B
        M.MINOR.L:
            order ← L
    endcase
    m ← LoadMemory(c,VirtAddr,msize,order)
    for i ← 0 to wsize-gsize by gsize
        q[0].t ← NULL
        for j ← 0 to vsize-gsize by gsize
            case op of
                W.MUL.MAT.F.16, W.MUL.MAT.F.32, W.MUL.MAT.F.64:
                    q[j+gsize] ← faddq[j], mul(gsize,m,i+wsize*
                    j_8..lgsize+1 ,b,j))
                W.MUL.MAT.C.F.16, W.MUL.MAT.C.F.32,
                W.MUL.MAT.C.F.64:
                    if (~i) & j & gsize = 0 then
                        k ← i-(j&gsize)+wsize*j_8..lgsize+1
                        q[j+gsize] ← faqq[j], mul(gsize,m,k,b,j))
                    else
                        k ← i+gsize+wsize*j_8..lgsize+1
                        q[j+gsize] ← fsubq[j], mul(gsize,m,k,b,j))
                    endif
            endcase
        endfor
        a_gsize-1+i..i ← q[vsize]
    endfor
    a_127..wsize ← 0
    RegWrite(rd, 128, a)
enddef
```

FIG. 17D-2

1780

Exceptions

Floating-point arithmetic
Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 17E

1810

Operation codes

W.MUL.MAT.G.8.B	Wide multiply matrix Galois bytes big-endian
W.MUL.MAT.G.8.L	Wide multiply matrix Galois bytes little-endian

Selection

class	op	size	order
Multiply matrix Galois	W.MUL.MAT.G	8	B L

Format

W.op.order ra=rc,rd,rb

ra=woporder(rc,rd,rb)

31 24	23 18	17 12	11 6	5 0
W.op.order	rd	rc	rb	ra
8	6	6	6	6

FIG. 18A

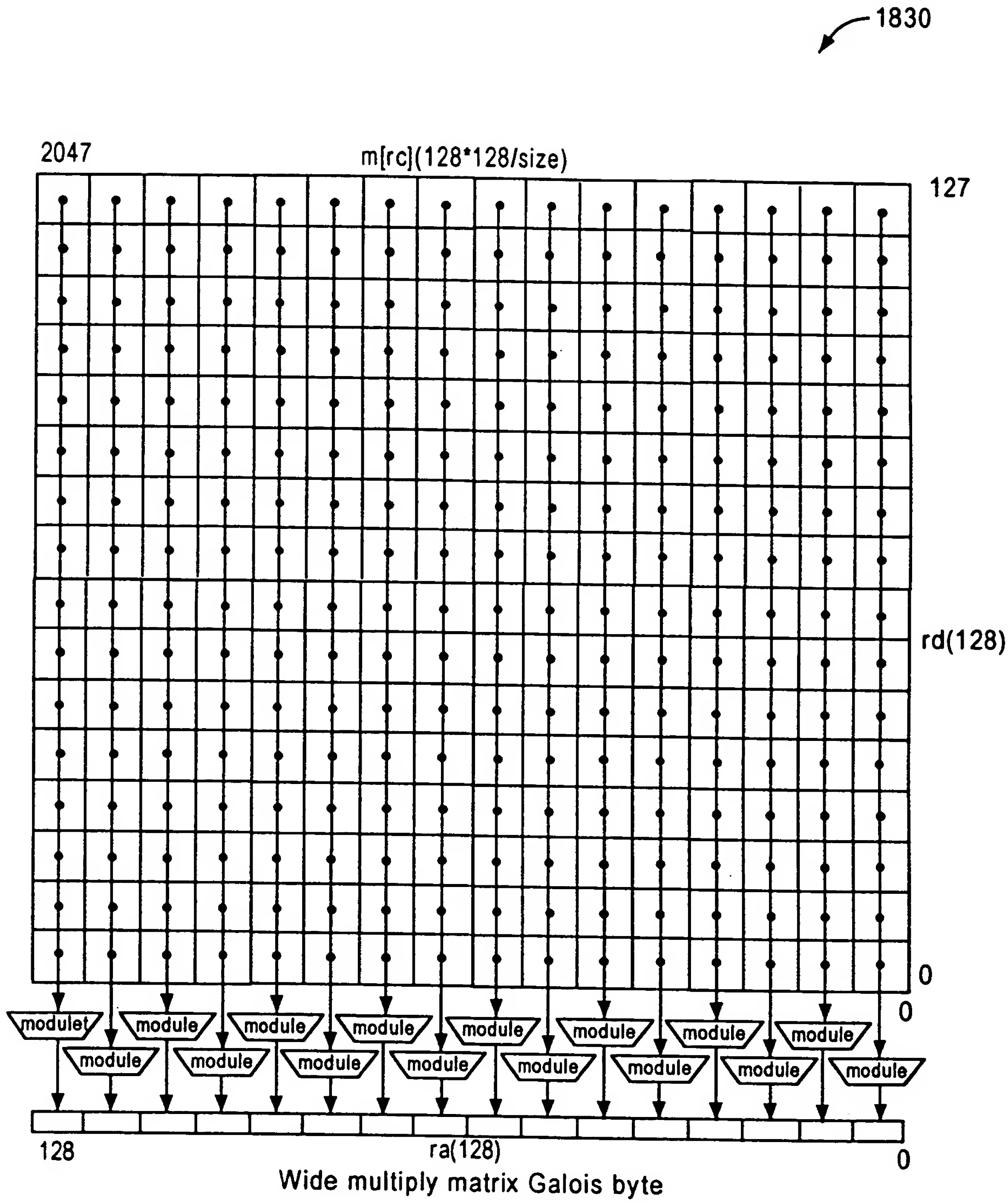

1830
2047
m[rc](128*128/size)
127
rd(128)
0
0
module
128
ra(128)
0
Wide multiply matrix Galois byte

FIG. 18B

1860

<u>Definition</u>

```
def c ← PolyMultiply(size,a,b) as
    p[0] ← 0^(2*size)
    for k ← 0 to size-1
        p[k+1] ← p[k] ^ a_k ? (0^(size-k) || b || 0^k) : 0^(2*size)
    endfor
    c ← p[size]
enddef

def c ← PolyResidue(size,a,b) as
    p[0] ← a
    for k ← size-1 to 0 by-1
        p[k-1] ← p[k] ^ p[0]_(size+k) ?(0^(size-k) || 1^1 || b || 0^k) : 0^(2*size)
    endfor
    c ← p[size]_(size-1..0)
enddef
def WideMultiplyMatrixGalois(op,gsize,rd,rc,rb,ra)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 64)
    b ← RegRead(rb,128)
    lgsize ← log(gsize)
    if c_(lgsize-4..0) ≠ 0 then
        raise AccessDisallowedByVirtualAddress
    endif
    if c_(3..lgsize-3) ≠ 0 then
        wsize ← (c and (0-c)) || 0^4
        t ← c and (c-1)
    else
        wsize ← 128
        t ← c
    endif
    lwsize ← log(wsize)
    if t_(lwsize+6-lgsize..lwsize-3) ≠ 0 then
        msize ← (t and (0-t)) || 0^4
        VirtAddr ← t and (t-1)
    else
        msize ← 128*wsize/gsize
        VirtAddr ← t
    endif
    case op of
        W.MUL.MAT.G.8.B:
            order ← B
        W.MUL.MAT.G.8.L:
            order ← L
    endcase
```

FIG. 18C-1

1860

```
    m ← LoadMemory(c, VirtAddr,msize,order)
    for i ← 0 wsize-gsize by gsize
        q[0] ← 0^(2*gsize)
        for j ← 0 to vsize-gsize by gsize
            k ← i+wsize*j_(8..lgsize)
            q[j+gsize] ← q[j] ^ PolyMultiply(gsize,m_(k+gsize-1..k) ,d_(j+gsize-1..j) )
        endfor

        a_(gsize-1+i..i) ← PolyResidue(gsize,q[vsize],b_(gsize-1..0) )
    endfor
    a_(127..wsize) ← 0
    RegWrite(ra,128, a)
enddef
```

FIG. 18C-2

1890

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 18D

1910

Operation codes

E.MUL.ADD.X	Ensemble multiply add extract
E.CON.X	Ensemble convolve extract

Format

E.op rd@rc,rb,ra

rd=gop(rd,rc,rb,ra)

31 24	23 18	17 12	11 6	5 0
E.op	rd	rc	rb	ra
8	6	6	6	6

FIG. 19A

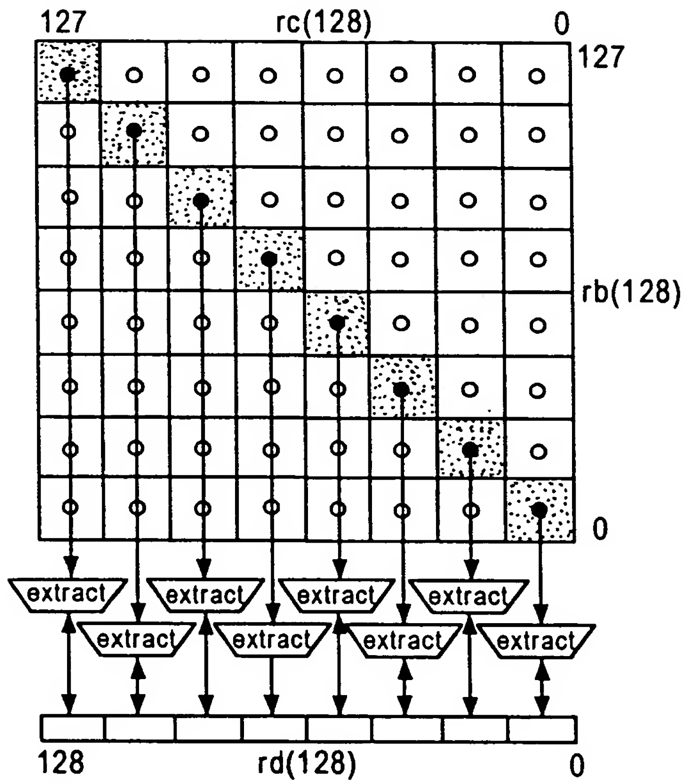
1910

Figures 19B and 20B has blank fields: should be.

fsize	dpos	x	s	n	m	l	rnd	gssp

FIG. 19B

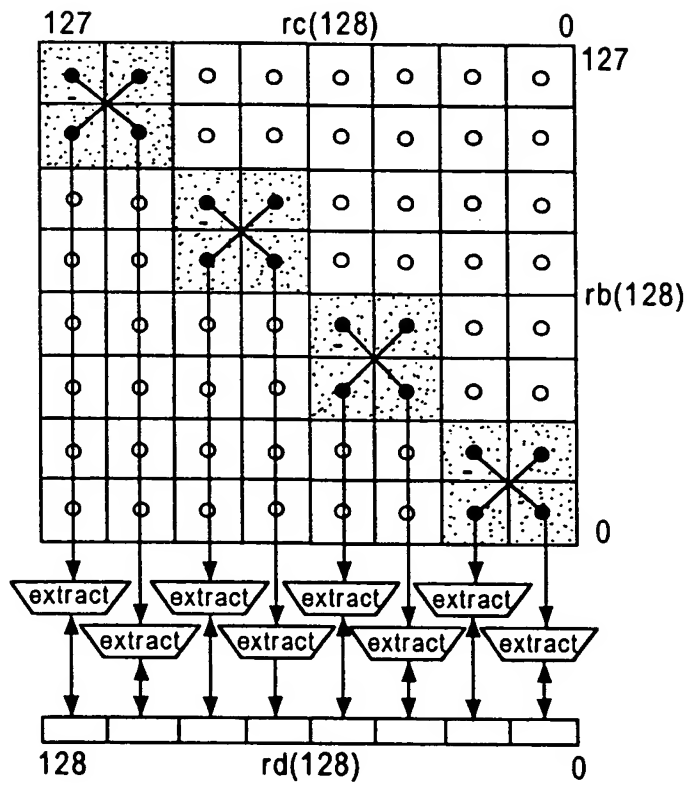
1930



Ensemble multiply add extract doublets

FIG. 19C

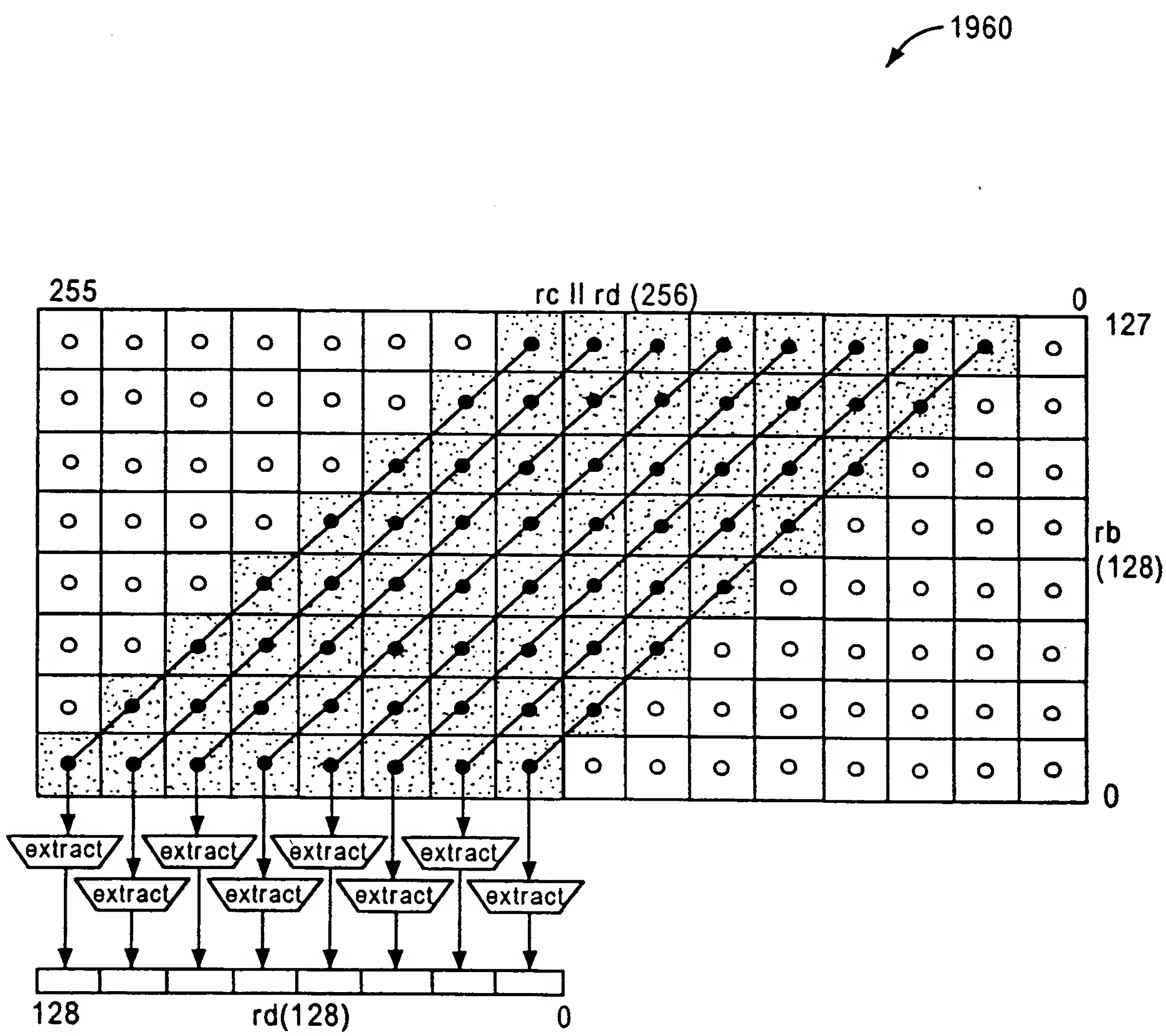
1945



Ensemble complex multiply add extract doublets

This ensemble-multiply-add-extract instructions (E.MUL.ADD.X), when the x bit is set, multiply the low-order 64 bits of each of the rc and rb registers and produce extended (double-size) results.

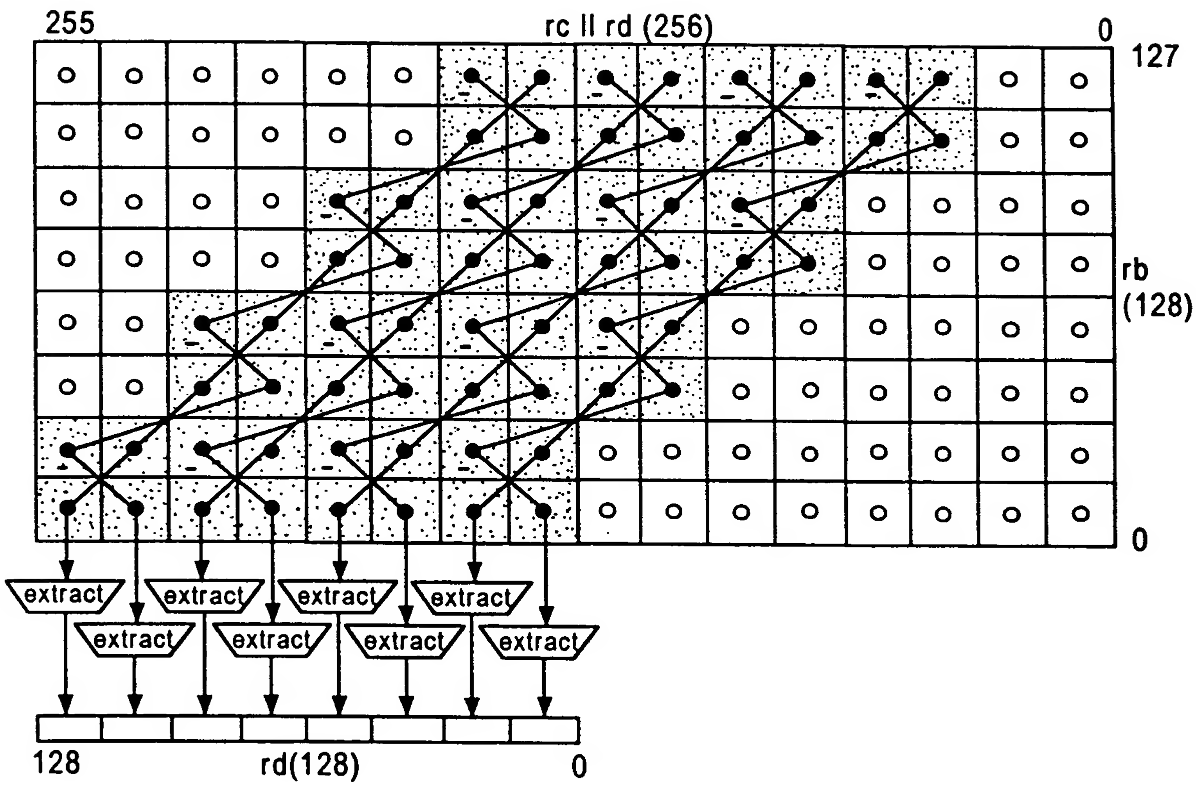
FIG. 19D



Ensemble convolve extract doublets

FIG. 19E

1975



Ensemble convolve extract complexdoublets

FIG. 19F

Definition

1990

```
def mul(size,h,vs,v,i,ws,w,j) as
    mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def EnsembleExtractInplace(op,ra,rb,rc,rd) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case b_{8..0} of
        0..255:
            sgsize ← 128
        256..383:
            sgsize ← 64
        384..447:
            sgsize ← 32
        448..479:
            sgsize ← 16
        480..495:
            sgsize ← 8
        496..503:
            sgsize ← 4
        504..507:
            sgsize ← 2
        508..511:
            sgsize ← 1
    endcase
    l ← a_{11}
    m ← a_{12}
    n ← a_{13}
    signed ← a_{14}
    x ← a_{15}
    case op of
        E.CON.X:
            if (sgsize < 8) then
                gsize ← 8
            elseif (sgsize*(n-1)*(x+1) > 128 then
                gsize ← 128/(n-1)/(x+1)
            else
                gsize ← sgsize
            endif
            lgsize ← log(gsize)
            wsize ← 128/(x+1)
```

FIG. 19G-1

1990

```
        vsize ← 128
        ds ← cs ← signed
        bs ← signed ^ m
        zs ← signed or m or n
        zsize ← gsize*(x+1)
        h ← (2*gsize) + log(vsize) - lgsize
        spos ← (a8..0) and (2*gsize-1)

E.MUL.ADD.X:
    if(sgsize < 9) then
        gsize ← 8
    elseif (sgsize*(n+1)*(x+1) > 128) then
        gsize ← 128/(n+1)/(x+1)
    else
        gsize ← sgsize
    endif
    ds ← signed
    cs ← signed ^ m
    zs ← signed or m or n
    zsize ← gsize*(x+1)
    h ← (2*gsize) + n
    spos ← (a8..0) and (2*gssize-1)
endcase
dpos ← (0|| a23..16) and (zsize-1)
r ← spos
sfsize ← (0|| a31..24) and (zsize-1)
tfsize ← (sfsize = 0) or ((sfsize+dpos) > zsize) ? zsize-dpos : sfsize
fsize ← (tfsize + spos > h) ? h - spos : tfsize
if (b10..9 = Z) and not as then
    rnd ← F
else
    rnd ← b10..9
endif
```

FIG. 19G-2

1990

```
for k ← 0 to wsize-zsize by zsize
    i ← k*gsize/zsize
    case op of
        E.CON.X:
            q[0] ← 0
            for j ← 0 to vsize-gsize by gsize
                if n then
                    if(~) & j &  gsize = 0 then
                        q[j+gsize] ← q[j] + mul(gsize,h,ms,m,i+
                        128-j,bs,b,j)
                    else
                        q[j+gsize] ← q[j] - mul(gsize,h,ms,i+
                        128-j+2*gsize,bs,b,j)
                    endif
                else
                    q[j+gsize] ← q[j] + mul(gsize,h,ms,m,i+
                    128-j,bs,b,j)
                endif
            endfor
            p ← q[vsize]
        E.MUL.ADD.X:
            di ← ((ds and d_{k+zize-1})^{h-zsize-r} || (d_{k+zsize-1..k}) || 0^r)
            if n then
                if ( i and gsize) = 0 then
                    p ← mul(gsize,h,ds,d,i,cs,c,i)-
mul(gsize,h,ds,d,i+gsize,cs,c,i+gsize)+di
                else

    p ← mul(gsize,h,ds,d,i,cs,c,i+gsize)+mul(gsize,h,ds,d,i,cs,c,i+gsize)+di
                endif
            else
                p ← mul(gsize,h,ds,d,i,cs,c,i) + di
            endif
    endcase
```

FIG. 19G-3

1990

```
case rnd of
    N:
        s ← 0^(h-r) || ~p_r || p_r^(r-1)
    Z:
        s ← 0^(h-r) || p_(h-1)^r
    F:
        s ← 0^h
    C:
        s ← 0^(h-r) || 1^r
endcase
v ← ((zs & p_(h-1)) || p) + (0 || s)
if (v_(h..r+fsize) = (zs & v_(r+fsize-1))^(h+1-r-fsize) or not (I and (op =
EXTRACT)) then
    w ← (zs & v_(r+fsize-1))^(zsize-fsize-dpos) || v_(fsize-1+r..r) || 0^dpos
else
    w ← (zs ? (v_h || ~v_h^(zsize-dpos-1)) : 1^(zsize-dpos)) || 0^dpos
endif
z_(zsize-1_k..k) ← w
endfor
RegWrite(rd, 128, z)
enddef
```

FIG. 19G-4

2010

Operation codes

E.MUL.X	Ensemble multiply extract
E.EXTRACT	Ensemble extract
E.SCAL.ADD.X	Ensemble scale and extract

Format

E.op ra=rd,rc,rb

ra=eop(rd,rc,rb)

31 ... 24	23 ... 18	17 ... 12	11 ... 6	5 ... 0
E.op	rd	rc	rb	ra
8	6	6	6	6

FIG. 20A

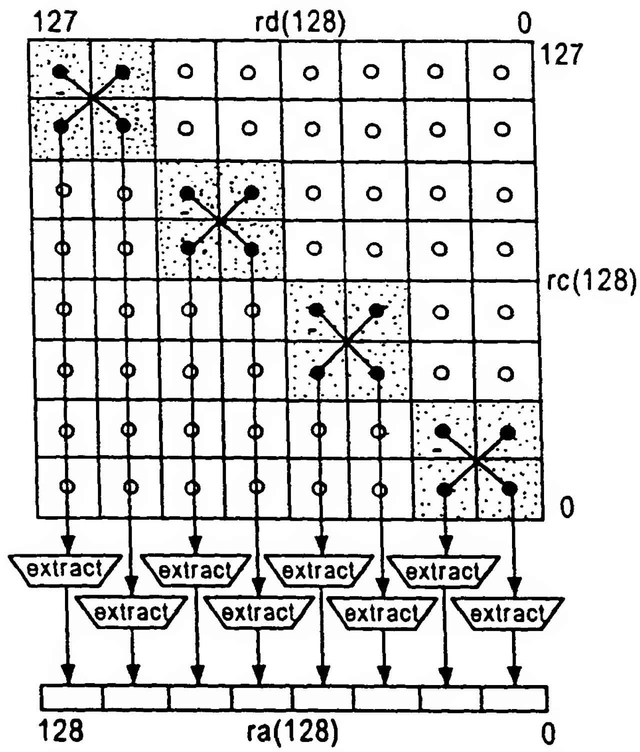
2015

Figures 19B and 20B has blank fields: should be.

fsize	dpos	x	s	n	m	l	rnd	gssp

FIG. 20B

2030

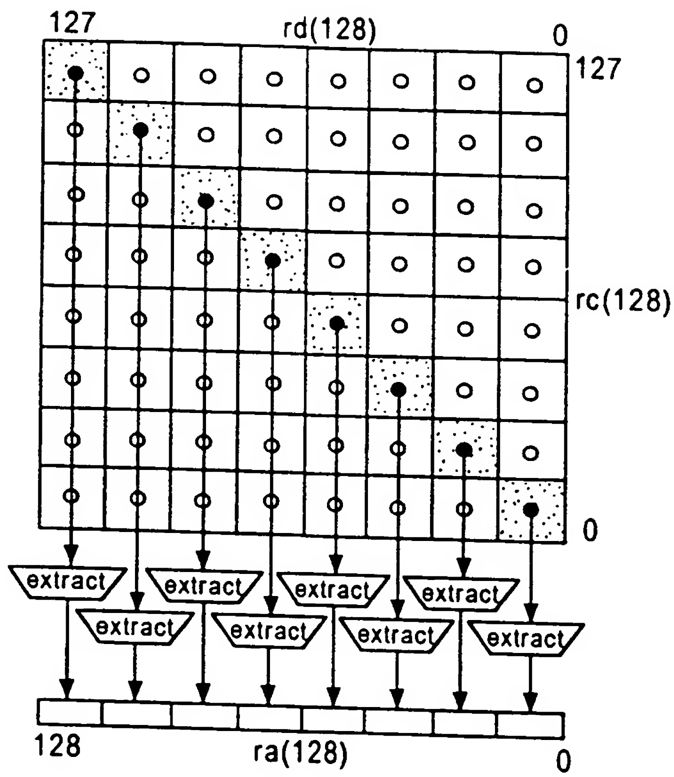


Ensemble complex multiply extract doublets

This ensemble-multiply-extract instructions (E.MUL.X), when the x bit is set, multiply the low-order 64 bits of each of the rc and rb registers and produce extended (double-size) results.

FIG. 20D

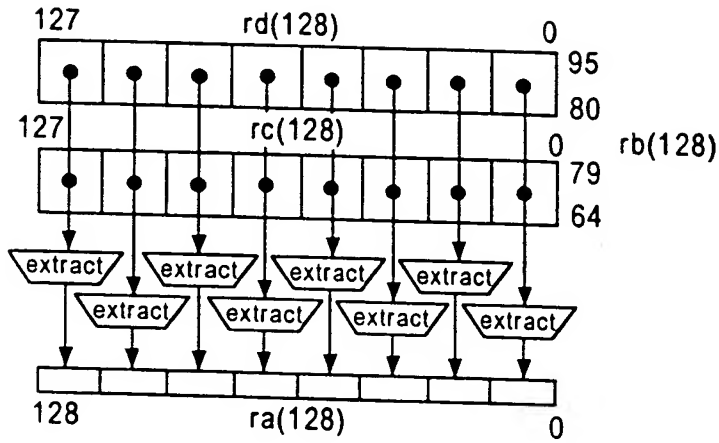
2020



127
rd(128)
0
127
rc(128)
0
extract
extract
extract
extract
extract
extract
extract
extract
128
ra(128)
0

FIG. 20C

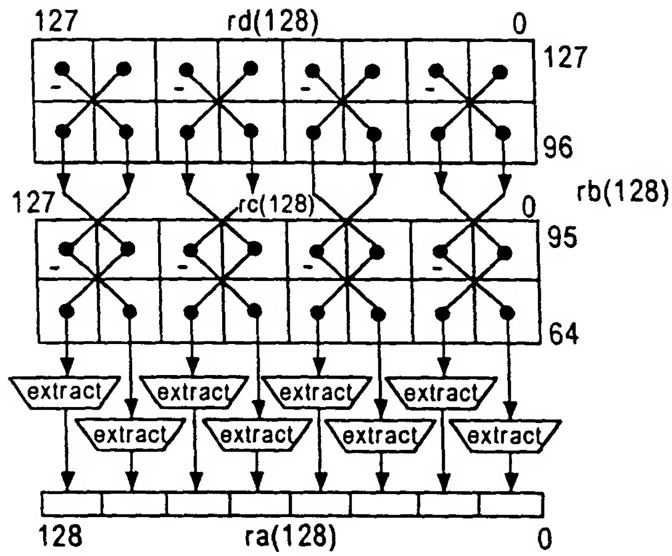
2040



Ensemble scale add extract doublets

FIG. 20E

2050

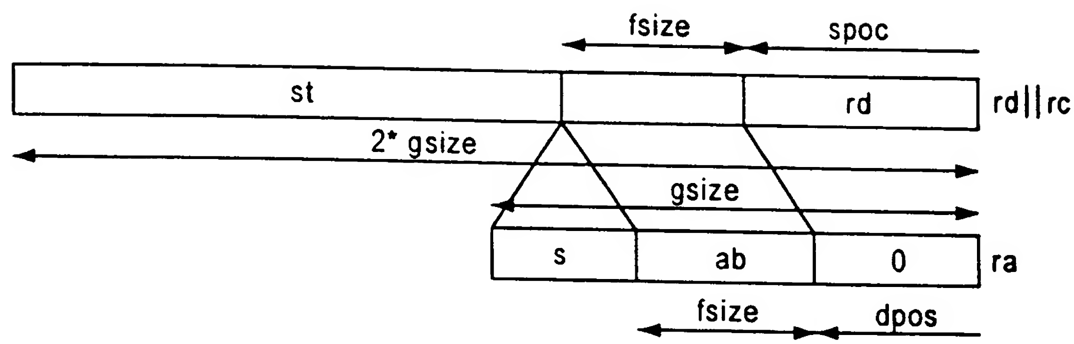


Ensemble complex scale add extract doublets

The ensemble-scale-add-extract instructions (E.SCLADD.X), when the x bit is set, multiply the low-order 64 bits of each of the rd and re registers by the rb register fields and produce extended (double-size) results.

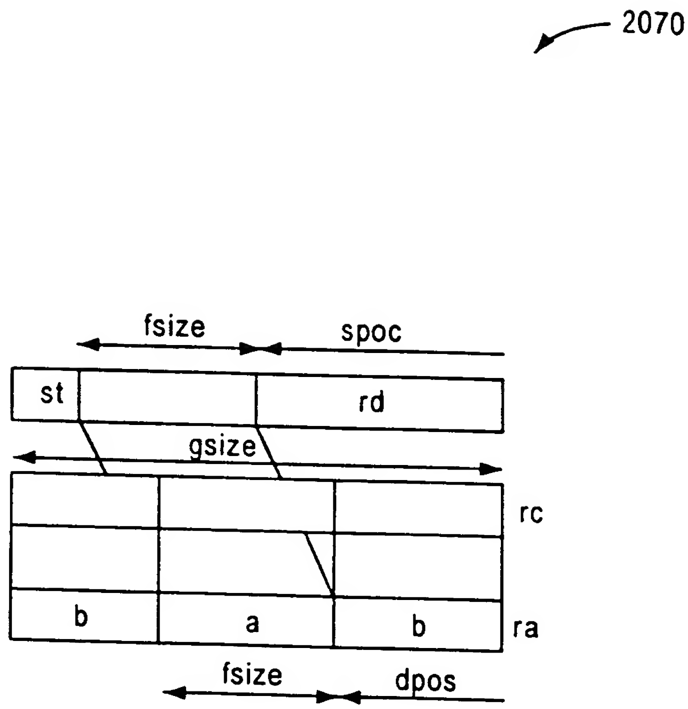
FIG. 20F

2060



Ensemble extract

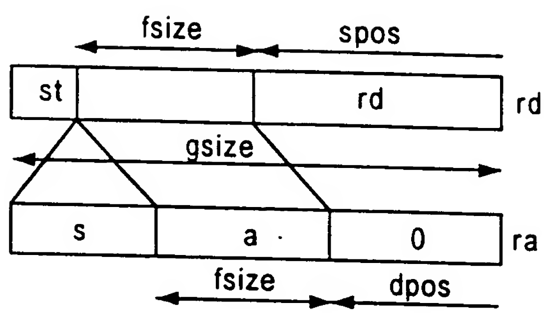
FIG. 20G



Ensemble merge extract

FIG. 20H

2080



Ensemble expand extract

FIG. 20I

2090

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
    mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def EnsembleExtract(op,ra,rb,rc,rd) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case b_{8..0} of
        0..255:
            sgsize ← 128
        256..383:
            sgsize ← 64
        384..447:
            sgsize ← 32
        448..479:
            sgsize ← 16
        480..495:
            sgsize ← 8
        496..503:
            sgsize ← 4
        504..507:
            sgsize ← 2
        508..511:
            sgsize ← 1
    endcase
    l ← b_11
    m ← b_12
    n ← b_13
    signed ← b_14
    x ← b_15
    case op of
        E.EXTRACT:
            gsize ← sgsize*2(2-(m or x))
            zsize ← sgsize
            h ← gsize
            as ← signed
            spos ← (b_{8..0}) and (gsize-1)
```

FIG. 20J-1

2090

```
    E.SCAL.ADD.X:
        if (sgsize < 8) then
            gsize ← 8
        elseif (sgsize*(n+1) > 32) then
            gsize ← 32/(n+1)
        else
            gsize ← sgsize
        endif
        ds ← cs ← signed
        bs ← signed ^ m
        as ← signed or m or n
        zsize ← gsize*(x+1)
        h ← (2*gsize) + 1 + n
        spos ← (b8..0) and (2*gsize-1)
    E.MUL.X:
        if (sgsize < 8) then
            gsize ← 8
        elseif (sgsize*(n+1)*(x+1) > 128) then
            gsize ← 128/(n+1)/(x+1)
        else
            gsize ← sgsize
        endif
        ds ← signed
        cs ← signed ^ m
        as ← signed or m or n
        zsize ← gsize*(x+1)
        h ← (2*gsize) + n
        spos ← (b8..0) and (2*gsize-1)
endcase
dpos ← (0|| b23..16) and (zsize-1)
r ← spos
sfsize ← (0|| b31..24) and (zsize-1)
tfsize ← (sfsize =0) or ((sfsize+dpos) > zsize) ? zsize-dpos : sfsize
fsize ← (tfsize + spos > h) ? h - spos : tfsize
if (b10..9=Z) and not as then
    rnd ← F
else
    rnd ← b
endif
```

FIG. 20J-2

2090

```
for j ← 0 to 128-zsize by zsize
    i ← j*gsize/zsize
    case op of
        E.EXTRACT:
            if m or x then
                p ← d_{gsize+i-1..i}
            else
                p ← (d || c)_{gsize+i-1..i}
            endif
        E.MUL.X:
            if n then
                if (i and gsize) = 0 then
                    p ← mul(gsize,h,ds,d,i,cs,c,i)-
mul(gsize,h,ds,d,i+gsize,cs,c,i+gsize)
                else
                    p ←
mul(gsize,h,ds,d,i,cs,c,i+gsize)+mul(gsize,h,ds,d,i,cs,c,i+gsize)
                endif
            else
                p ← mul(gsize,h,ds,d,i,cs,c,i)
            endif
        E.SCAL.ADD.X:
            if n then
                if (i and gsize) = 0 then
                    p ← mul(gsize,h,ds,d,i,bs,b,64+2*gsize)
                        + mul(gsize,h,cs,c,i,bs,b,64)
                        - mul(gsize,h,ds,d,i+gsize,bs,b,64+3*gsize)
                        - mul(gsize,h,cs,c,i+gsize,bs,b,64+gsize)
                else
                    p ← mul(gsize,h,ds,d,i,bs,b,64+3*gsize)
                        + mul(gsize,h,cs,c,i,bs,b,64+gsize)
                        + mul(gsize,h,ds,d,i+gsize,bs,b,64+2*gsize)
                        + mul(gsize,h,cs,c,i+gsize,bs,b,64)
                endif
            else
                p ← mul(gsize,h,ds,d,i,bs,b,64+gsize) + mul(gsize
                    ,h,cs,c,i,bs,b,64)
            endif
    endcase
```

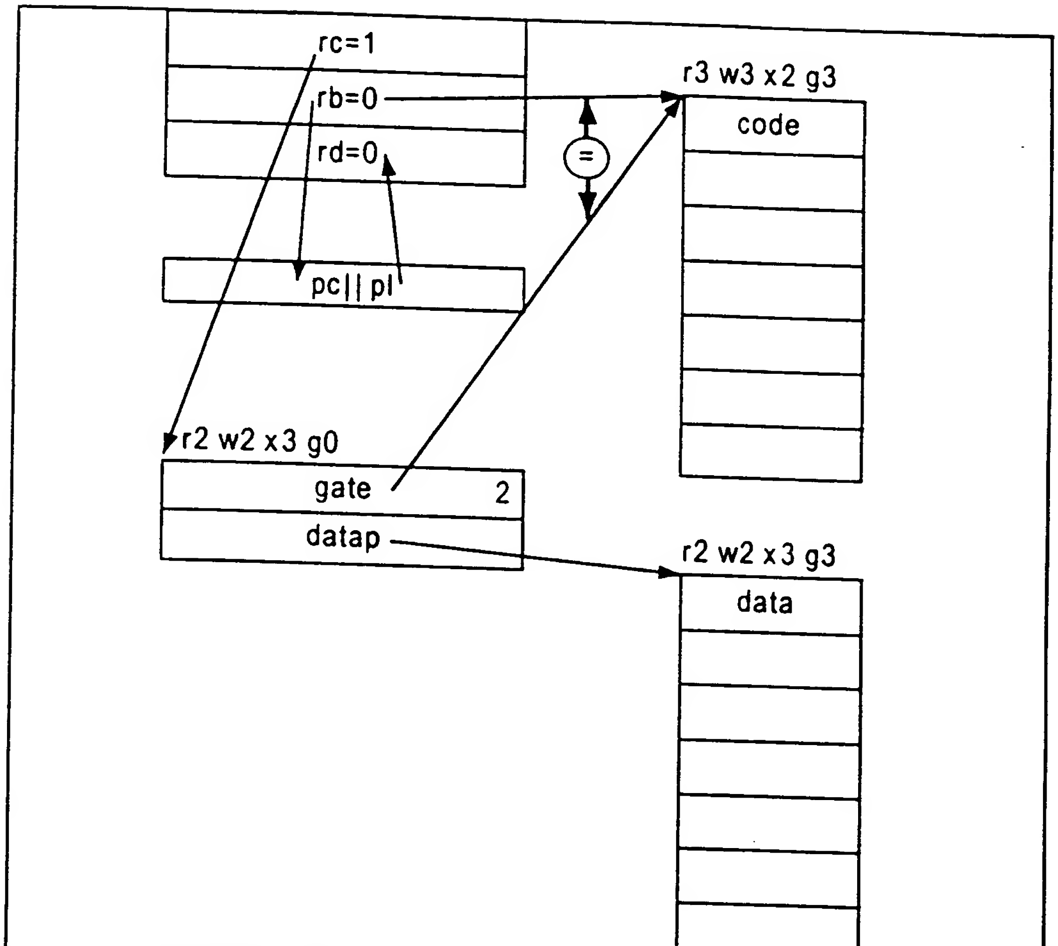
FIG. 20J-3

2090

```
        case rnd of
            N:
                s ← 0^(h-r) || ~p_r || p_r^(r-1)
            Z:
                s ← 0^(h-r) || p_(h-1)^r
            F:
                s ← 0^h
            C:
                s ← 0^(h-r) || 1^r
        endcase
        v ← ((as & p_(h-1))||p) + (0||s)
        if (v_(h..r+fsize) = (as & v_(r+fsize-1))^(h+1-r-fsize) ) or not (l and (op =
                        E.EXTRACT)) then
            w ← (as & v_(r+fsize=1))^(zsize-fsize-dpos) || v_(fsize-1+r..r) || 0^dpos
        else
            w ← (s ? (v_h || ~v_h^(zsize-dpos-1)) : 1^(zsize-dpos)) || 0^dpos
        endif
        if m and (op = E.EXTRACT) then
            z_(zsize-1+j..j) ← c_(asize-1+j..dpos+fsize+j) || w_(dpos+fsize-1..dpos) ||
                            c_(dpos-1+j..j)
        else
            z_(zsize-1+j..j) ← w
        endif
    endfor
    RegWrite(ra, 128, z)
enddef
```

FIG. 20J-4

2110



Gateway with pointers to code and data spaces

FIG. 21A

2130

Typical dynamic-linked, inter-gateway calling sequence:
caller:

```
caller  AA.DDI          sp@-size      // allocate caller stack frame
        S.I.64.A        lp,sp,off
        S.I.64.A        dp,sp,off
        ...
        L.I.64.A        lp=dp,off     // load lp
        L.I.64.A        dp=dp,off     // load dp
        B.GATE
        L.I.64.A        dp,sp,off
        ...(code using dp)
        L.I.64.A        lp=sp,off     // restore original lp register
        A.ADDI          sp=size       // deallocate caller stack frame
        B               lp            // return
```

callee (non-leaf):

```
calee:  L.I.64.A        dp=dp,off     // load dp with data pointer
        S.I.64.A        sp,dp,off
        L.I.64.A        sp=dp,off     // new stack pointer
        S.I.64.A        lp,sp,off
        S.I.64.A        dp,sp,off
        ...(using dp)
        L.I.64.A        dp,sp,off
        ...(code using dp)
        L.I.64.A        lp=sp,off     // restore original lp register
        L.I.64.A        sp=sp,off     // restore original sp register
        B.DOWN          lp
```

callee (leak, no stack):

```
callee: ...(using dp)
        B.DOWN          lp
```

FIG. 21B

2160

Operation codes

B.GATE	Branch gateway

Equivalencies

B.GATE	←	B.GATE 0

Format

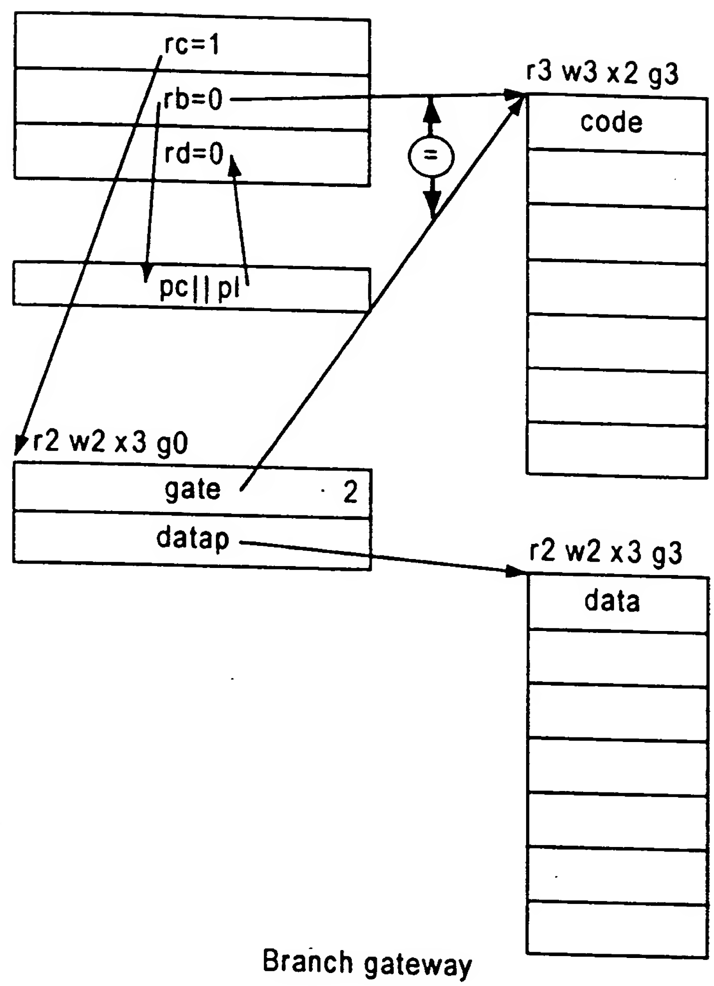
B.GATE rb

bgate(rb)

31 24	23 18	17 12	11 6	5 0
B.MINOR	0	1	rb	B.GATE
8	6	6	6	6

FIG. 21C

2170



rc=1
rb=0
rd=0
=
r3 w3 x2 g3
code
pc||pl
r2 w2 x3 g0
gate
2
datap
r2 w2 x3 g3
data
Branch gateway

FIG. 21D

2190

<u>Definition</u>

```
def BranchGateway(rd,rc,rb) as
        c ← RegRead(rc, 64)
        b ← RegRead(rb, 64)
        if (rd ≠ 0) or (rc ≠ 1) then
                raise ReservedInstruction
        endif
        if c2..0 ≠ 0 then
                raise AccessDisallowedByVirtualAddress
        endif
        d ← ProgramCounter63..2+1 || PrivilegeLevel
        if PrivilegeLevel < b1..0 then
                m ← LoadMemoryG(c,c,64,L)
                if b ≠ m then
                        raise GatewayDisallowed
                endif
                PrivilegeLevel ← b1..0
        endif
        ProgramCounter ← b63..2 || 0^2
        RegWrite(rd, 64, d)
        raise TakenBranch
enddef
```

FIG. 21E

2199

Exceptions

Reserved Instruction
Gateway disallowed
Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

FIG. 21F

2210

Operation codes

E.SCAL.ADD.F.16	Ensemble scale add floating-point half
E.SCAL.ADD.F.32	Ensemble scale add floating-point single
E.SCAL.ADD.F.64	Ensemble scale add floating-point double

Selection

class	op	prec		
scale add	E.SCAL.ADD.F	16	32	64

Format

E.op.prec ra=rd,rc,rb

ra=eopprec(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
E.op.prec	rd	rc	rb	ra
8	6	6	6	6

FIG. 22A

2230

Definition

```
def EnsembleFloatingPointTernary(op,prec,rd,rc,rb,ra) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-prec by prec
        di ← F(prec,d_{i+prec-1..i})
        ci ← F(prec,c_{i+prec-1..i})
        ai ← fadd(fmul(di, F(prec,b_{prec-1..0})), fmul(ci, F(prec,b_{2*prec-1..prec})))
        a_{i+prec-1..i} ← PackF(prec, ai, none)
    endfor
    RegWrite(ra, 128, a)
enddef
```

FIG. 22B

2310

Operation codes

G.BOOLEAN	Group boolean

Selection

operation	function (binary)	function (decimal)
d	11110000	240
c	11001100	204
b	10101010	176
d&c&b	10000000	128
(d&c)|b	11101010	234
d|c|b	11111110	254
d?c:b	11001010	202
d^c^b	10010110	150
~d^c^b	01101001	105
0	00000000	0

Format

G.BOOLEAN rd@trc,trb,f

rd=gbooleani(rd,rc,rb,f)

31 … 25	24	23 … 18	17 … 12	11 … 6	5 … 0
G.BOOLEAN	ih	rd	rc	rb	il
7	1	6	6	6	6

FIG. 23A

2320

```
if f6=f5 then
        if f2=f1 then
                if f2 then
                        rc ← max(trc,trb)
                        rb ← min(trc,trb)
                else
                        rc ← min(trc,trb)
                        rb ← max(trc,trb)
                endif
                ih ← 0
                il ← 0 || f6 || f7 || f4 || f3 || f0
        else
                if f2 then
                        rc ← trb
                        rb ← trc
                else
                        rc ← trc
                        rb ← trb
                endif
                ih ← 0
                il ← 1 || f6 || f7 || f4 || f3 || f0
        endif
else
        ih ← 1
        if f6 then
                rc ← trb
                rb ← trc
                il ← f1 || f2 || f7 || f4 || f3 || f0
        else
                rc ← trc
                rb ← trb
                il ← f2 || f1 || f7 || f4 || f3 || f0
        endif
endif
```

FIG. 23B

2330

Definition

```
def GroupBoolean (ih,rd,rc,rb,il)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    if ih=0 then
        if il5=0 then
            f ← il3 || il4 || il4 || il2 || il1 || (rc>rb)^2 || il0
        else
            f ← il3 || il4 || il4 || il2 || il1 || 0 || 1 || il0
        endif
    else
        f ← il3 || 0 || 1 || il2 || il1 || il5 || il4 || il0
    endif
    for i ← 0 to 127 by size
        ai ← f(di||ci||bi)
    endfor
    RegWrite(rd, 128, a)
enddef
```

FIG. 23C

2410

Operation codes

B.HINT	Branch Hint

Format

B.HINT badd,count,rd

bhint(badd,count,rd)

31 24	23 18	17 12	11 6	5 0
B.MINOR	rd	count	simm	B.HINT
8	6	6	6	6

simm ← badd-pc-4

FIG. 24A

2430

<u>Definition</u>

```
def BranchHint(rd,count,simm) as
        d ← RegRead(rd, 64)
        if (d1..0) ≠ 0 then
                raise AccessDisallowedByVirtualAddress
        endif
        FetchHint(ProgramCounter +4 + (0 || simm || 0^2), d63..2 || 0^2, count)
enddef
```

FIG. 24B

2460

Exceptions

Access disallowed by virtual address

FIG. 24C

2510

Operation codes

E.SINK.F.16	Ensemble convert floating-point doublets from half nearest default
E.SINK.F.16C	Ensemble convert floating-point doublets from half ceiling
E.SINK.F.16.C.D	Ensemble convert floating-point doublets from half ceiling default
E.SINK.F.16.F	Ensemble convert floating-point doublets from half floor
E.SINK.F.16.F.D	Ensemble convert floating-point doublets from half floor default
E.SINK.F.16.N	Ensemble convert floating-point doublets from half nearest
E.SINK.F.16.X	Ensemble convert floating-point doublets from half exact
E.SINK.F.16.Z	Ensemble convert floating-point doublets from half zero
E.SINK.F.16.Z.D	Ensemble convert floating-point doublets from half zero default
E.SINK.F.32	Ensemble convert floating-point quadlets from single nearest default
E.SINK.F.32.C	Ensemble convert floating-point quadlets from single ceiling
E.SINK.F.32.C.D	Ensemble convert floating-point quadlets from single ceiling default
E.SINK.F.32.F	Ensemble convert floating-point quadlets from single floor
E.SINK.F.32.F.D	Ensemble convert floating-point quadlets from single floor default
E.SINK.F.32.N	Ensemble convert floating-point quadlets from single nearest
E.SINK.F.32.X	Ensemble convert floating-point quadlets from single exact
E.SINK.F.32.Z	Ensemble convert floating-point quadlets from single zero
E.SINK.F.32.Z.D	Ensemble convert floating-point quadlets from single zero default
E.SINK.F.64	Ensemble convert floating-point octlets from double nearest default
E.SINK.F.64.C	Ensemble convert floating-point octlets from double ceiling
E.SINK.F.64.C.D	Ensemble convert floating-point octlets from double ceiling default
E.SINK.F.64.F	Ensemble convert floating-point octlets from double floor
E.SINK.F.64.F.D	Ensemble convert floating-point octlets from double floor default
E.SINK.F.64.N	Ensemble convert floating-point octlets from double nearest
E.SINK.F.64.X	Ensemble convert floating-point octlets from double exact
E.SINK.F.64.Z	Ensemble convert floating-point octlets from double zero
E.SINK.F.64.Z.D	Ensemble convert floating-point octlets from double zero default
E.SINK.F.128	Ensemble convert floating-point hexlet from quad nearest default
E.SINK.F.128.C	Ensemble convert floating-point hexlet from quad ceiling
E.SINK.F.128.C.D	Ensemble convert floating-point hexlet from quad ceiling default
E.SINK.F.128.F	Ensemble convert floating-point hexlet from quad floor
E.SINK.F.128.F.D	Ensemble convert floating-point hexlet from quad floor default
E.SINK.F.128.N	Ensemble convert floating-point hexlet from quad nearest
E.SINK.F.128.X	Ensemble convert floating-point hexlet from quad exact
E.SINK.F.128.Z	Ensemble convert floating-point hexlet from quad zero
E.SINK.F.128.Z.D	Ensemble convert floating-point hexlet from quad zero default

FIG. 25A-1

2510

Selection

	op	prec	round/trap
integer from float	SINK	16 32 64 128	NONE C F N X Z C.D F.D Z.D

Format

E.SINK.F.prec.rnd rd=rc

rd=esinkfprecrnd(rc)

31 … 24	23 … 18	17 … 12	11 … 6	5 … 0
E.prec	rd	rc	E.SINK.F.rnd	E.UNARY
8	6	6	6	6

FIG. 25A-2

2530

Definition

```
def EnsemleSinkFloatingPoint(prec,round,rd,rc) as
    c ← RegRead(rc, 128)
    for i ← 0 to 128-prec by prec
        ci ← F(prec,c_{i+prec-1..i})
        a_{i+prec-1..i} ← fsinkr(prec, ci, round)
    endfor
    RegWrite[rd, 128, a]
enddef
```

FIG. 25B

2560

Exceptions

Floating-point arithmetic

FIG. 25C

2570

```
Definition
def eb ← ebits(prec) as
    case pref of
        16:
            eb ← 5
        32:
            eb ← 8
        64:
            eb ← 11
        128:
            eb ← 15
    endcase
enddef

def eb ← ebias(prec)as
    eb ← 0|| 1^(ebits(prec)-1)
enddef

def fb ← fbits(prec) as
    fb ← prec - 1 - eb
enddef

def a ← F(prec, ai) as
    a.s ← ai_(prec-1)
    ae ← ai_(prec-2..fbits(prec))
    af ← ai_(fbits(prec)-1..0)
    if ae = 1^(ebits(prec)) then
        if af = 0 then
            a.t ← INFINITY
        elseif af_(fbits(prec)-1) then
            a.t ← SNaN
            a.e ← -fbits(prec)
            a.f ← 1 || af_(fbits(prec)-1..0)
        else
            a.t ← QNaN
            a.e ← -fbits(prec)
            a.f ← af
        endif
    elseif ae = 0 then
        if af = 0 then
            a.t ← ZERO
```

FIG. 25D-1

2570

```
            else
                  a.t ← NORM
                  a.e ← 1-ebias(pec)-fbits(prec)
                  a.f ← 0|| af
            endif
      else
            a.t ← NORM
            a.e ← ae-ebias(prec)-fbits(prec)
            a.f ← 1|| af
      endif
enddef

def a ← DEFAULTQNAN as
      a.s ← 0
      a.t ← QNAN
      a.e ← -1
      a.f ← 1
endder

def a ← DEFAULTSNAN as
      a.s ← 0
      a.t ← SNAN
      a.e ← -1
      a.f ← 1
enddef
```

FIG. 25D-2

2570

```
def fadd(a,b) as faddr(a,b,N) endder

def c ← faddr(a,b,round) as
    if a.t=NORM and b.t=NORM then
        // d,e are a,b with exponent aligned and fraction adjusted
        if a.e > b.e then
            d ← a
            e.t ← b.t
            e.s ← b.s
            e.e ← a.e
            e.f ← b.f || 0^(a.e-b.e)
        else if a.e < b.e then
            d.t ← a.t
            d.s ← a.s
            d.e ← b.e
            d.f ← a.f || 0^(b.e-a.e)
            e ← b
        endif
        c.t ← d.t
        c.e ← d.e
        if d.s = e.s then
            c.s ← d.s
            c.f ← d.f + e.f
        elseif d.f > e.f then
            c.s ← d.s
            c.f ← d.f - e.f
        elseif d.f < e.f then
            c.s ← e.s
            c.f ← e.f - d.f
        else
            c.s ← r=F
            c.t ← ZERO
        endif
```

FIG. 25D-3

2570

```
// priority is given to be operand for NaN propagation
elseif (b.t=SNAN) or (b.t=QNAN) then
      c ← b
elseif (a.t=SNAN) or (a.t=QNAN) then
      c ← a
elseif a.t=ZERO and b.t=ZERO then
      c.t ← ZERO
      c.s ← (a.s and b.s) or (round=F and (a.s or b.s))
// NULL values are like zero, but do not combine with ZERO to alter sign
elseif a.t=ZERO or a.t=NULL then
      c ← b
elseif b.t=ZERO or b.t=NULL then
      c ← a
elseif a.t=INFINITY and b.t=INFINITY then
      if a.s ≠ b.s then
            c ← DEFAULTSNAN // Invalid
      else
            c ← a
      endif
elseif a.t=INFINITY then
      c ← a
elseif b.t=INFINITY then
      c ← b
else
      assert FALSE // should have covered all the cases above
endif
enddef

def b ← fneg(a) as
      b.s ← ~a.s
      b.t ← a.t
      b.e ← a.e
      b.f ← a.f
enddef

def fsub(a,b) as fsubr(a,b,N) enddef

def fsubr(a,b,round) as faddr(a,fneg(b),round) enddef

def frsub(a,b) as frsubr(a,b,N) enddef

def frsubr(a,b,round) as faddr(fneg(a),b,round) enddef
```

FIG. 25D-4

2570

```
def c ← fcom(a,b) as
    if (a.t-SNAN) or (a.t=QNAN) or (b.t=SNAN) or (b.t=QNAN) then
        c ← U
    elseif a.t=INFINITY and b.t=INFINITY then
        if a.s ≠ b.s then
            c ← (a.s=0) ? G: L
        else
            c ← E
        endif
    elseif a.t=INFINITY then
        c ← (a.s=0) ? G: L
    elseif b.t=INFINITY then
        c ← (b.s=0) ? L
    elseif a.t=NORM and b.t=NORM then
        if a.s ≠ b.s then
            c ← (a.s=0) ? G: L
        else
            if a.e > b.e then
                af ← a.f
                bf ← b.f||0^(a.e-b.e)
            else
                af ← a.f||0^(b.e-a.e)
                bf ← b.f
            endif
            if af = bf then
                c ← E
            else
                c ← ((a.s=0) ^ (af > bf)) ? G : L
            endif
        endif
    elseif a.t=NORM then
        c ← (a.s=0) ? G: L
    elseif b.t=NORM then
        c ← (b.s=0) ? G: L
    elseif a.t=ZERO and b.t=ZERO then
        c ← E
    else
        assert FALSE // should have covered al the cases above
    endif
enddef
```

FIG. 25D-5

2570

```
def c ← fmul(a,b) as
    if a.t=NORM and b.t=NORM then
        c.s ← a.s ^ b.s
        c.t ← NORM
        c.e ← a.e + b.e
        c.f ← a.f * b.f
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← b.t
        c.e ← b.e
        c.f ← b.f
    elseif (a.t=SNAN) or (a.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← a.t
        c.e ← a.e
        c.f ← a.f
    elseif a.t=ZERO and b.t=INFINITY then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=INFINITY and b.t=ZERO then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=ZERO or b.t=ZERO then
        c.s ← a.s ^ b.s
        c.t ← ZERO
    else
        assert FALSE // should have covered al the cases above
    endif
enddef
```

FIG. 25D-6

2570

```
def c     fdivr(a,b) as
    if a.t=NORM and b.t=NORM then
        c.s ← a.s ^ b.s
        c.t ← NORM
        c.e ← a.e - b.e + 256
        c.f ← (a.f    0    ) / b.f
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← b.t
        c.e ← b.e
        c.f ← b.f
    elseif (a.t=SNAN) or (a.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← a.t
        c.e ← a.e
        c.f ← a.f
    elseif a.t=ZERO and b.t=INFINITY then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=INFINITY and b.t=INFINITY then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=ZERO then
        c.s ← a.s ^ b.s
        c.t ← ZERO
    elseif a.t=INFINITY then
        c.s ← a.s ^ b.s
        c.t ← INFINITY
    else
        assert FALSE // should have covered al the cases above
    endif
enddef

def msb ← findmsb(a) as
    MAXF ← 2^18 // Largest possible f value after matrix multiply
    for j ← 0 to MAXF
        if a_{MAXF-1..j} = (0^{MAXF-1-j} || 1) then
            msb ← j
        endif
    endfor
enddef
```

FIG. 25D-7

2570

```
Def ai ← PackF(prec,a,round) as
    case a.t of
        NORM:
            msb ← findmsb(a.f)
            m ← msb-1-fbits(prec) //1sb for normal
            rdn ← -ebias(prec)-a.e-1-fbits(prec) // 1sb if a denormal
            rb ← (m > rdn) ? rn : rdn
            if rb < 0 then
                aifr ← a.f_{msb-1..0} || 0^{-rb}
                eadj ← 0
            else
                case round of
                    C:
                        s ← 0^{msb-rb} || (~a.s)^{rb}
                    F:
                        s ← 0^{msb-rb} || (a.s)^{rb}
                    N, NONE:
                        s ← 0^{msb-rb} || ~a.f_{rb} || a.f_{rb}^{rb-1}
                    X:
                        if a.f_{rb-1..0} ≠ 0 then
                            raise FloatingPointArithmetic // Inexact
                        endif
                        s ← 0
                    Z:
                        s ← 0
                endcase
                v ← (0 || a.f_{msb..0}) + (0 || s)
                if v_{msb}=1 then
                    aifr ← v_{msb-1..rb}
                    eadj ← 0
                else
                    aifr ← 0^{fbits(prec)}
                    eadj ← 1
                endif
            endif
            aien ← a.e + msb - 1 + eadj + ebias(prec)
            if aien ≤ 0 then
                if round = NONE then
                    ai ← a.s || 0^{ebits(prec)} || aifr
                else
                    raise FloatingPointArithmetic //Underflow
```

FIG. 25D-8

2570

```
        endif
    elseif aien ≥ 1^ebits(prec) then
        if round = NONE then
            //default: round-to-nearest overflow handling
            ai ← a.s || 1^ebits(prec) || 0^fbits(prec)
        else
            raise FloatingPointArithmetic // Overflow
        endif
    else
        ai ← a.s || aien_ebits(prec)-1..0 || aifr
    endif

    SNAN:
        if round ≠ NONE then
            raise FloatingPointArithmetic //Invalid
        endif
        if -a.e < fbits(prec) then
            ai ← a.s || 1^ebits(prec) || a.f_-a.e-1..0 || 0^fbits(prec)+a.e
        else
            lsb ← a.f_-a.e-1-fbits(prec)+1..0 ≠ 0
            ai ← a.s || 1^ebits(prec) || a.f_-a.e-1..-a.e-1-fbits(prec)+2 || 1sb
        endif
    QNAN:
        if -a.e < fbits(prec) then
            ai ← a.s || 1^ebits(prec) || a.f_-a.e-1..0 || 0^fbits(prec)+a.e
        else
            1sb ← a.f_-a.e-1-fbits(prec)+1..0 ≠ 0
            ai ← a.s || 1^ebits(prec) || a.f_-a.e-1..-a.e-1-fbits(prec)+2 || 1sb
        endif
    ZERO:
        ai ← a.s || 0^ebits(prec) || 0^fbits(prec)
    INFINITY:
        ai ← a.s || 1^ebits(prec) || 0^fbits(prec)
  endcase
defdef
```

FIG. 25D-9

2570

```
Def ai ← fsinkr(prec, a, round) as
    case a.t of
        NORM:
            msb ← findmsb(a.f)
            rb ← -a.e
            if rb ≤ 0 then
                aifr ← a.f_{msb..0} || 0^{-rb}
                aims ← msb - rb
            else
                case round of
                    C,C.D:
                            s ← 0^{msb-rb} || (~ai.s)^{rb}
                    F,F.D:
                            s ← 0^{msb-rb} || (ai.s)^{rb}
                    N, NONE:
                            s ← 0^{msb-rb} || ~ai.f_{rb} || ai.f_{rb}^{rb-1}
                    X:
                            if ai.f_{rb-1..0} ≠ 0 then
                                raise FloatingPointArithmetic // Inexact
                            endif
                            s ← 0
                    Z, Z.D:
                            s ← 0
                endcase
                v ← (0 || a.f_{msb..0}) + (0 || s)
                if v_{msb}=1 then
                    aims ← msb + 1 - rb
                else
                    aims ← msb - rb
                endif
                aifr ← v_{aims..rb}
            endif
            if aims > prec then
                case round of
                    C.D, F.D, NONE,  Z.D:
                        ai ← a.s || (~as)^{prec-1}
                    C,F,N,X,Z:
                        raise FloatingPointArithmetic // Overflow
                endcase
```

FIG. 25D-10

2570

```
            elseif a.s = 0 then
                ai ← aifr
            else
                ai ← -aifr
            endif
        ZERO:
            ai ← 0^prec
        SNAN, QNAN:
            case round of
                C.D, F.D, NONE, Z.D:
                    ai ← 0^prec
                C, F, N, X, Z:
                    raise FloatingPoint Arithmetic // Invalid

            endcase
        INFINITY:
            case round of
                C.D, F.D, NONE, Z.D:
                    ai ← a.s || (~as)^prec-1
                C, F, N, X, Z:
                    raise FloatingPointArithmetic // Invalid
            endcase
    endcase
enddef


def c    frecrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fdiv(b,a))
enddef

def c ← frsqrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fsqr(fdiv(b,a)))
enddef
```

FIG. 25D-11

2570

```
def c ← fest(a) as
      if (a.t=NORM) then
            msb ← findmsb(a.f)
            a.e ← a.e + msb - 13
            a.f ← a.f_msb..msb-12 || 1
      else
            c ← a
      endif
enddef

def ← fsqr(a) as
      if (a.t=NORM) and (a.s=0) then
            c.s ← 0
            c.t ← NORM
            if (a.e_0 =1) then
                  c.e ← (a.e-127) / 2
                  c.f ← sqr(a.f || 0^127 )
            else
                  c.e ← (a.e-128) / 2
                  c.f ← sqr(a.f || 0^128 )
            endif
      elseif (a.t=SNAN) or (a.t-QNAN) or a.t=ZERO or ((a.t=INFINITY) and
            (a.s=0)) then
            c ← a
      elseir ((a.t=NORM) or (a.t=INFINITY)) and (a.s=1) then
            c ← DEFAULTSNAN // Invalid
      else
            assert FALSE // should have covered a1 the cases above
      endif
enddef
```

FIG. 25D-12

Operation codes

G.ADD.8	Group add bytes
G.ADD.16	Group add doublets
G.ADD.32	Group add quadlets
G.ADD.64	Group add octlets
G.ADD.128	Group add hexlet
G.ADD.L.8	Group add limit signed bytes
G.ADD.L.16	Group add limit signed doublets
G.ADD.L.32	Group add limit signed quadlets
G.ADD.L.64	Group add limit signed octlets
G.ADD.L.128	Group add limit signed hexlet
G.ADD.L.U.8	Group add limit unsigned bytes
G.ADD.L.U.16	Group add limit unsigned doublets
G.ADD.L.U.32	Group add limit unsigned quadlets
G.ADD.L.U.64	Group add limit unsigned octlets
G.ADD.L.U.128	Group add limit unsigned hexlet
G.ADD.8.O	Group add signed bytes check overflow
G.ADD.16.O	Group add signed doublets check overflow
G.ADD.32.O	Group add signed quadlets check overflow
G.ADD.64.O	Group add signed octlets check overflow
G.ADD.128.O	Group add signed hexlet check overflow
G.ADD.U.8.O	Group add unsigned bytes check overflow
G.ADD.U.16.O	Group add unsigned doublets check overflow
G.ADD.U.32.O	Group add unsigned quadlets check overflow
G.ADD.U.64.O	Group add unsigned octlets check overflow
G.ADD.U.128.O	Group add unsigned hexlet check overflow

FIG. 26A

Format

G.op.size	rd=rc,rb

rd=gopsize(rc,rb)

31 … 24	23 … 18	17 … 12	11 … 6	5 … 0
G.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

FIG. 26B

Definition

```
def Group(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.ADD:
            for i ← 0 to 128-size by size
                ai+size-1..i ← ci+size-1..i + bi+size-1..i
            endfor
        G.ADD.L:
            for i ← 0 to 128-size by size
                t ← (ci+size-1 || ci+size-1..i) + (bi+size-1 || bi+size-1..i)
                ai+size-1..i ← (tsize ≠ tsize-1) ? (tsize || tsize^size-1) : tsize-1..0
            endfor
        G.ADD.L.U:
            for i ← 0 to 128-size by size
                t ← (0^1 || ci+size-1..i) + (0^1 || bi+size-1..i)
                ai+size-1..i ← (tsize ≠ 0) ? (1^size) : tsize-1..0
            endfor
        G.ADD.O:
            for i ← 0 to 128-size by size
                t ← (ci+size-1 || ci+size-1..i) + (bi+size-1 || bi+size-1..i)
                if tsize ≠ tsize-1 then
                    raise FixedPointArithmetic
                endif
                ai+size-1..i ← tsize-1..0
            endfor
        G.ADD.U.O:
            for i ← 0 to 128-size by size
                t ← (0^1 || ci+size-1..i) + (0^1 || bi+size-1..i)
                if tsize ≠ 0 then
                    raise FixedPointArithmetic
                endif
                ai+size-1..i ← tsize-1..0
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

FIG. 26C

Operation codes

G.SET.AND.E.8	Group set and equal zero bytes
G.SET.AND.E.16	Group set and equal zero doublets
G.SET.AND.E.32	Group set and equal zero quadlets
G.SET.AND.E.64	Group set and equal zero octlets
G.SET.AND.E.128	Group set and equal zero hexlet
G.SET.AND.NE.8	Group set and not equal zero bytes
G.SET.AND.NE.16	Group set and not equal zero doublets
G.SET.AND.NE.32	Group set and not equal zero quadlets
G.SET.AND.NE.64	Group set and not equal zero octlets
G.SET.AND.NE.128	Group set and not equal zero hexlet
G.SET.E.8	Group set equal bytes
G.SET.E.16	Group set equal doublets
G.SET.E.32	Group set equal quadlets
G.SET.E.64	Group set equal octlets
G.SET.E.128	Group set equal hexlet
G.SET.GE.8	Group set greater equal signed bytes
G.SET.GE.16	Group set greater equal signed doublets
G.SET.GE.32	Group set greater equal signed quadlets
G.SET.GE.64	Group set greater equal signed octlets
G.SET.GE.128	Group set greater equal signed hexlet
G.SET.GE.U.8	Group set greater equal unsigned bytes
G.SET.GE.U.16	Group set greater equal unsigned doublets
G.SET.GE.U.32	Group set greater equal unsigned quadlets
G.SET.GE.U.64	Group set greater equal unsigned octlets
G.SET.GE.U.128	Group set greater equal unsigned hexlet
G.SET.L.8	Group set signed less bytes
G.SET.L.16	Group set signed less doublets
G.SET.L.32	Group set signed less quadlets
G.SET.L.64	Group set signed less octlets
G.SET.L.128	Group set signed less hexlet
G.SET.L.U.8	Group set less unsigned bytes
G.SET.L.U.16	Group set less unsigned doublets
G.SET.L.U.32	Group set less unsigned quadlets
G.SET.L.U.64	Group set less unsigned octlets
G.SET.L.U.128	Group set less unsigned hexlet
G.SET.NE.8	Group set not equal bytes
G.SET.NE.16	Group set not equal doublets
G.SET.NE.32	Group set not equal quadlets
G.SET.NE.64	Group set not equal octlets
G.SET.NE.128	Group set not equal hexlet
G.SUB.8	Group subtract bytes
G.SUB.8.O	Group subtract signed bytes check overflow

FIG. 27A-1

G.SUB.16	Group subtract doublets
G.SUB.16.O	Group subtract signed doublets check overflow
G.SUB.32	Group subtract quadlets
G.SUB.32.O	Group subtract signed quadlets check overflow
G.SUB.64	Group subtract octlets
G.SUB.64.O	Group subtract signed octlets check overflow
G.SUB.128	Group subtract hexlet
G.SUB.128.O	Group subtract signed hexlet check overflow
G.SUB.L.8	Group subtract limit signed bytes
G.SUB.L.16	Group subtract limit signed doublets
G.SUB.L.32	Group subtract limit signed quadlets
G.SUB.L.64	Group subtract limit signed octlets
G.SUB.L.128	Group subtract limit signed hexlet
G.SUB.L.U.8	Group subtract limit unsigned bytes
G.SUB.L.U.16	Group subtract limit unsigned doublets
G.SUB.L.U.32	Group subtract limit unsigned quadlets
G.SUB.L.U.64	Group subtract limit unsigned octlets
G.SUB.L.U.128	Group subtract limit unsigned hexlet
G.SUB.U.8.O	Group subtract unsigned bytes check overflow
G.SUB.U.16.O	Group subtract unsigned doublets check overflow
G.SUB.U.32.O	Group subtract unsigned quadlets check overflow
G.SUB.U.64.O	Group subtract unsigned octlets check overflow
G.SUB.U.128.O	Group subtract unsigned hexlet check overflow

FIG. 27A-2

Format

G.op.size   rd=rb,rc

rd=gopsize(rb,rc)

31 ... 24	23 ... 18	17 ... 12	11 ... 6	5 ... 0
G.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

FIG. 27B

Definition

```
def GroupReversed(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.SUB:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← b_{i+size-1..i} - c_{i+size-1..i}
            endfor
        G.SUB.L:
            for i ← 0 to 128-size by size
                t ← (b_{i+size-1} || b_{i+size-1..i}) - (c_{i+size-1} || c_{i+size-1..i})
                a_{i+size-1..i} ← (t_{size} ≠ t_{size-1}) ? (t_{size} || t_{size}^{size-1}) : t_{size-1..0}
            endfor
        G.SUB.LU:
            for i ← 0 to 128-size by size
                t ← (0^1 || b_{i+size-1..i}) - (0^1 || c_{i+size-1..i})
                a_{i+size-1..i} ← (t_{size} ≠ 0) ? 0^{size}: t_{size-1..0}
            endfor
        G.SUB.O:
            for i ← 0 to 128-size by size
                t ← (b_{i+size-1} || b_{i+size-1..i}) - (c_{i+size-1} || c_{i+size-1..i})
                if (t_{size} ≠ t_{size-1}) then
                    raise FixedPointArithmetic
                endif
                a_{i+size-1..i} ← t_{size-1..0}
            endfor
        G.SUB.U.O:
            for i ← 0 to 128-size by size
                t ← (0^1 || b_{i+size-1..i}) - (0^1 || c_{i+size-1..i})
                if (t_{size} ≠ 0) then
                    raise FixedPointArithmetic
                endif
                a_{i+size-1..i} ← t_{size-1..0}
            endfor
        G.SET.E:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← (b_{i+size-1..i} = c_{i+size-1..i})^{size}
            endfor
        G.SET.NE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← (b_{i+size-1..i} ≠ c_{i+size-1..i})^{size}
            endfor
        G.SET.AND.E:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((b_{i+size-1..i} and c_{i+size-1..i}) = 0)^{size}
            endfor
```

FIG. 27C-1

```
        G.SET.AND.NE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((b_{i+size-1..i} and c_{i+size-1..i}) ≠ 0)^size
            endfor
        G.SET.L:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} < 0) : (b_{i+size-1..i} < c_{i+size-1..i}))^size
            endfor
        G.SET.GE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} ≥ 0) : (b_{i+size-1..i} ≥ c_{i+size-1..i}))^size
            endfor
        G.SET.L.U:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} > 0) :
                    ((0 || b_{i+size-1..i}) < (0 || c_{i+size-1..i})))^size
            endfor
        G.SET.GE.U:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} ≤ 0) :
                    ((0 || b_{i+size-1..i}) ≥ (0 || c_{i+size-1..i})))^size
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

FIG. 27C-2

Operation codes

E.CON.8	Ensemble convolve signed bytes
E.CON.16	Ensemble convolve signed doublets
E.CON.32	Ensemble convolve signed quadlets
E.CON.64	Ensemble convolve signed octlets
E.CON.C.8	Ensemble convolve complex bytes
E.CON.C.16	Ensemble convolve complex doublets
E.CON.C.32	Ensemble convolve complex quadlets
E.CON.M.8	Ensemble convolve mixed-signed bytes
E.CON.M.16	Ensemble convolve mixed-signed doublets
E.CON.M.32	Ensemble convolve mixed-signed quadlets
E.CON.M.64	Ensemble convolve mixed-signed octlets
E.CON.U.8	Ensemble convolve unsigned bytes
E.CON.U.16	Ensemble convolve unsigned doublets
E.CON.U.32	Ensemble convolve unsigned quadlets
E.CON.U.64	Ensemble convolve unsigned octlets
E.DIV.64	Ensemble divide signed octlets
E.DIV.U.64	Ensemble divide unsigned octlets
E.MUL.8	Ensemble multiply signed bytes
E.MUL.16	Ensemble multiply signed doublets
E.MUL.32	Ensemble multiply signed quadlets
E.MUL.64	Ensemble multiply signed octlets
E.MUL.SUM.8	Ensemble multiply sum signed bytes
E.MUL.SUM.16	Ensemble multiply sum signed doublets
E.MUL.SUM.32	Ensemble multiply sum signed quadlets
E.MUL.SUM.64	Ensemble multiply sum signed octlets
E.MUL.C.8	Ensemble complex multiply bytes
E.MUL.C.16	Ensemble complex multiply doublets
E.MUL.C.32	Ensemble complex multiply quadlets
E.MUL.M.8	Ensemble multiply mixed-signed bytes
E.MUL.M.16	Ensemble multiply mixed-signed doublets
E.MUL.M.32	Ensemble multiply mixed-signed quadlets
E.MUL.M.64	Ensemble multiply mixed-signed octlets
E.MUL.P.8	Ensemble multiply polynomial bytes
E.MUL.P.16	Ensemble multiply polynomial doublets
E.MUL.P.32	Ensemble multiply polynomial quadlets
E.MUL.P.64	Ensemble multiply polynomial octlets
E.MUL.SUM.C.8	Ensemble multiply sum complex bytes
E.MUL.SUM.C.16	Ensemble multiply sum complex doublets
E.MUL.SUM.C.32	Ensemble multiply sum complex quadlets
E.MUL.SUM.M.8	Ensemble multiply sum mixed-signed bytes
E.MUL.SUM.M.16	Ensemble multiply sum mixed-signed doublets
E.MUL.SUM.M.32	Ensemble multiply sum mixed-signed quadlets
E.MUL.SUM.M.64	Ensemble multiply sum mixed-signed octlets

FIG. 28A-1

E.MUL.SUM.U.8	Ensemble multiply sum unsigned bytes
E.MUL.SUM.U.16	Ensemble multiply sum unsigned doublets
E.MUL.SUM.U.32	Ensemble multiply sum unsigned quadlets
E.MUL.SUM.U.64	Ensemble multiply sum unsigned octlets
E.MUL.U.8	Ensemble multiply unsigned bytes
E.MUL.U.16	Ensemble multiply unsigned doublets
E.MUL.U.32	Ensemble multiply unsigned quadlets
E.MUL.U.64	Ensemble multiply unsigned octlets

FIG. 28A-2

Format

E.op.size rd=rc,rb

rd=eopsize(rc,rb)

31 24	23 18	17 12	11 6	5 0
E.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

FIG. 28B

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
    mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def c ← PolyMultiply(size,a,b) as
    p[0] ← 0^{2*size}
    for k ← 0 to size-1
        p[k+1] ← p[k] ^ a_k ? (0^{size-k} || b || 0^k) : 0^{2*size}
    endfor
    c ← p[size]
enddef

def Ensemble(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        E.MUL:, E.MUL.C:, EMUL.SUM, E.MUL.SUM.C, E.CON, E.CON.C, E.DIV:
            cs ← bs ← 1
        E.MUL.M:, EMUL.SUM.M, E.CON.M:
            cs ← 0
            bs ← 1
        E.MUL.U:, EMUL.SUM.U, E.CON.U, E.DIV.U, E.MUL.P:
            cs ← bs ← 0
    endcase
    case op of
        E.MUL, E.MUL.U, E.MUL.M:
            for i ← 0 to 64-size by size
                d_{2*(i+size)-1..2*i} ← mul(size,2*size,cs,c,i,bs,b,i)
            endfor
        E.MUL.P:
            for i ← 0 to 64-size by size
                d_{2*(i+size)-1..2*i} ← PolyMultiply(size,c_{size-1+i..i},b_{size-1+i..i})
            endfor
        E.MUL.C:
            for i ← 0 to 64-size by size
                if (i and size) = 0 then
                    p ← mul(size,2*size,1,c,i,1,b,i) - mul(size,2*size,1,c,i+size,1,b,i+size)
                else
                    p ← mul(size,2*size,1,c,i,1,b,i+size) + mul(size,2*size,1,c,i,1,b,i+size)
                endif
                d_{2*(i+size)-1..2*i} ← p
            endfor
        E.MUL.SUM, E.MUL.SUM.U, E.MUL.SUM.M:
            p[0] ← 0^{128}
            for i ← 0 to 128-size by size
                p[i+size] ← p[i] + mul(size,128,cs,c,i,bs,b,i)
            endfor
```

FIG. 28C-1

```
a ← p[128]
E.MUL.SUM.C:
    p[0] ← 0^64
    p[size] ← 0^64
    for i ← 0 to 128-size by size
        if (i and size) = 0 then
            p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i)
                              - mul(size,64,1,c,i+size,1,b,i+size)
        else
            p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i+size)
                              + mul(size,64,1,c,i+size,1,b,i)
        endif
    endfor
    a ← p[128+size] || p[128]

E.CON, E.CON.U, E.CON.M:
    p[0] ← 0^128
    for j ← 0 to 64-size by size
        for i ← 0 to 64-size by size
            p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                mul(size,2*size,cs,c,i+64-j,bs,b,j)
        endfor
    endfor
    a ← p[64]
E.CON.C:
    p[0] ← 0^128
    for j ← 0 to 64-size by size
        for i ← 0 to 64-size by size
            if ((~i) and j and size) = 0 then
                p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                    mul(size,2*size,1,c,i+64-j,1,b,j)
            else
                p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i -
                    mul(size,2*size,1,c,i+64-j+2*size,1,b,j)
            endif
        endfor
    endfor
    a ← p[64]
E.DIV:
    if (b = 0) or ( (c = (1||0^63)) and (b = 1^64) ) then
        a ← undefined
```

FIG. 28C-2

```
else
                q ← c / b
                r ← c - q*b
                a ← r63..0 || q63..0
            endif
        E.DIV.U:
            if b = 0 then
                a ← undefined
            else
                q ← (0 || c) / (0 || b)
                r ← c - (0 || q)*(0 || b)
                a ← r63..0 || q63..0
            endif
    endcase
    RegWrite(rd, 128, a)
enddef
```

FIG. 28C-3

Floating-point function Definitions

```
def eb ← ebits(prec) as
	case pref of
		16:
			eb ← 5
		32:
			eb ← 8
		64:
			eb ← 11
		128:
			eb ← 15
	endcase
enddef

def eb ← ebias(prec) as
	eb ← 0 || 1^(ebits(prec)-1)
enddef

def fb ← fbits(prec) as
	fb ← prec – 1 – eb
enddef

def a ← F(prec, ai) as
	a.s ← ai_(prec-1)
	ae ← ai_(prec-2..fbits(prec))
	af ← ai_(fbits(prec)-1..0)
	if ae = 1^(ebits(prec)) then
		if af = 0 then
			a.t ← INFINITY
		elseif af_(fbits(prec)-1) then
			a.t ← SNaN
			a.e ← -fbits(prec)
			a.f ← 1 || af_(fbits(prec)-2..0)
		else
			a.t ← QNaN
			a.e ← -fbits(prec)
			a.f ← af
		endif
```

FIG. 29-1

```
        elseif ae = 0 then
                if af = 0 then
                        a.t ← ZERO
                else
                        a.t ← NORM
                        a.e ← 1-ebias(prec)-fbits(prec)
                        a.f ← 0 || af
                endif
        else
                a.t ← NORM
                a.e ← ae-ebias(prec)-fbits(prec)
                a.f ← 1 || af
        endif
enddef

def a ← DEFAULTQNAN as
        a.s ← 0
        a.t ← QNAN
        a.e ← -1
        a.f ← 1
enddef

def a ← DEFAULTSNAN as
        a.s ← 0
        a.t ← SNAN
        a.e ← -1
        a.f ← 1
enddef

def fadd(a,b) as faddr(a,b,N) enddef

def c ← faddr(a,b,round) as
        if a.t=NORM and b.t=NORM then
                // d,e are a,b with exponent aligned and fraction adjusted
                if a.e > b.e then
                        d ← a
                        e.t ← b.t
                        e.s ← b.s
                        e.e ← a.e
                        e.f ← b.f || 0^(a.e-b.e)
                else if a.e < b.e then
                        d.t ← a.t
                        d.s ← a.s
                        d.e ← b.e
                        d.f ← a.f || 0^(b.e-a.e)
                        e ← b
```

FIG. 29-2

```
        endif
        c.t ← d.t
        c.e ← d.e
        if d.s = e.s then
            c.s ← d.s
            c.f ← d.f + e.f
        elseif d.f > e.f then
            c.s ← d.s
            c.f ← d.f − e.f
        elseif d.f < e.f then
            c.s ← e.s
            c.f ← e.f − d.f
        else
            c.s ← r=F
            c.t ← ZERO
        endif
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
        c ← b
    elseif (a.t=SNAN) or (a.t=QNAN) then
        c ← a
    elseif a.t=ZERO and b.t=ZERO then
        c.t ← ZERO
        c.s ← (a.s and b.s) or (round=F and (a.s or b.s))
    // NULL values are like zero, but do not combine with ZERO to alter sign
    elseif a.t=ZERO or a.t=NULL then
        c ← b
    elseif b.t=ZERO or b.t=NULL then
        c ← a
    elseif a.t=INFINITY and b.t=INFINITY then
        if a.s ≠ b.s then
            c ← DEFAULTSNAN // Invalid
        else
            c ← a
        endif
    elseif a.t=INFINITY then
        c ← a
    elseif b.t=INFINITY then
        c ← b
    else
        assert FALSE // should have covered al the cases above
    endif
enddef

def b ← fneg(a) as
    b.s ← ~a.s
    b.t ← a.t
    b.e ← a.e
    b.f ← a.f
enddef
```

FIG. 29-3

```
def fsubr(a,b,round) as faddr(a,fneg(b),round) enddef

def frsub(a,b) as frsubr(a,b,N) enddef

def frsubr(a,b,round) as faddr(fneg(a),b,round) enddef

def c ← fcom(a,b) as
    if (a.t=SNAN) or (a.t=QNAN) or (b.t=SNAN) or (b.t=QNAN) then
        c ← U
    elseif a.t=INFINITY and b.t=INFINITY then
        if a.s ≠ b.s then
            c ← (a.s=0) ? G: L

        else
            c ← E
        endif
    elseif a.t=INFINITY then
        c ← (a.s=0) ? G: L
    elseif b.t=INFINITY then
        c ← (b.s=0) ? G: L
    elseif a.t=NORM and b.t=NORM then
        if a.s ≠ b.s then
            c ← (a.s=0) ? G: L
        else
            if a.e > b.e then
                af ← a.f
                bf ← b.f || 0^(a.e-b.e)
            else
                af ← a.f || 0^(b.e-a.e)
                bf ← b.f
            endif
            if af = bf then
                c ← E
            else
                c ← ((a.s=0) ^ (af > bf)) ? G : L
            endif
        endif
    elseif a.t=NORM then
        c ← (a.s=0) ? G: L
    elseif b.t=NORM then
        c ← (b.s=0) ? G: L
    elseif a.t=ZERO and b.t=ZERO then
        c ← E
    else
        assert FALSE // should have covered al the cases above
    endif
enddef
```

FIG. 29-4

```
def c ← fmul(a,b) as
    if a.t=NORM and b.t=NORM then
        c.s ← a.s ^ b.s
        c.t ← NORM
        c.e ← a.e + b.e
        c.f ← a.f * b.f
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← b.t
        c.e ← b.e
        c.f ← b.f
    elseif (a.t=SNAN) or (a.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← a.t
        c.e ← a.e
        c.f ← a.f
    elseif a.t=ZERO and b.t=INFINITY then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=INFINITY and b.t=ZERO then
        c ← DEFAULTSNAN // Invalid
    elseif a.t=ZERO or b.t=ZERO then
        c.s ← a.s ^ b.s
        c.t ← ZERO
    else
        assert FALSE // should have covered al the cases above
    endif
enddef

def c ← fdivr(a,b) as
    if a.t=NORM and b.t=NORM then
        c.s ← a.s ^ b.s
        c.t ← NORM
        c.e ← a.e - b.e + 256
        c.f ← (a.f || 0^256) / b.f
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← b.t
        c.e ← b.e
        c.f ← b.f
    elseif (a.t=SNAN) or (a.t=QNAN) then
        c.s ← a.s ^ b.s
        c.t ← a.t
        c.e ← a.e
        c.f ← a.f
```

FIG. 29-5

```
        elseif a.t=ZERO and b.t=ZERO then
                c ← DEFAULTSNAN // Invalid
        elseif a.t=INFINITY and b.t=INFINITY then
                c ← DEFAULTSNAN // Invalid
        elseif a.t=ZERO then
                c.s ← a.s ^ b.s
                c.t ← ZERO
        elseif a.t=INFINITY then
                c.s ← a.s ^ b.s
                c.t ← INFINITY
        else
                assert FALSE // should have covered al the cases above
        endif
enddef

def msb ← findmsb(a) as
        MAXF ← 2^18 // Largest possible f value after matrix multiply
        for j ← 0 to MAXF
                if a_{MAXF-1..j} = (0^{MAXF-1-j} || 1) then
                        msb ← j
                endif
        endfor
enddef

def ai ← PackF(prec,a,round) as
        case a.t of
                NORM:
                        msb ← findmsb(a.f)
                        rn ← msb-1-fbits(prec) // lsb for normal
                        rdn ← -ebias(prec)-a.e-1-fbits(prec) // lsb if a denormal
                        rb ← (rn > rdn) ? rn : rdn
```

FIG. 29-6

```
if rb ≤ 0 then
    aifr ← a.f_{msb-1..0} || 0^{-rb}
    eadj ← 0
else
    case round of
        C:
            s ← 0^{msb-rb} || (~a.s)^{rb}
        F:
            s ← 0^{msb-rb} || (a.s)^{rb}
        N, NONE:
            s ← 0^{msb-rb} || ~a.f_{rb} || a.f_{rb}^{rb-1}
        X:
            if a.f_{rb-1..0} ≠ 0 then
                raise FloatingPointArithmetic // Inexact
            endif
            s ← 0
        Z:
            s ← 0
    endcase
    v ← (0||a.f_{msb..0}) + (0||s)
    if v_{msb} = 1 then
        aifr ← v_{msb-1..rb}
        eadj ← 0
    else
        aifr ← 0^{fbits(prec)}
        eadj ← 1
    endif
endif
aien ← a.e + msb − 1 + eadj + ebias(prec)
if aien ≤ 0 then
    if round = NONE then
        ai ← a.s || 0^{ebits(prec)} || aifr
    else
        raise FloatingPointArithmetic //Underflow
    endif
elseif aien ≥ 1^{ebits(prec)} then
    if round = NONE then
        //default: round-to-nearest overflow handling
        ai ← a.s || 1^{ebits(prec)} || 0^{fbits(prec)}
    else
        raise FloatingPointArithmetic //Underflow
    endif
else
    ai ← a.s || aien_{ebits(prec)-1..0} || aifr
endif
```

FIG. 29-7

```
        SNAN:
            if round ≠ NONE then
                raise FloatingPointArithmetic //Invalid
            endif
            if −a.e < fbits(prec) then
                ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..0} || 0^{fbits(prec)+a.e}
            else
                lsb ← a.f_{-a.e-1-fbits(prec)+1..0} ≠ 0
                ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..-a.e-1-fbits(prec)+2} || lsb
            endif
        QNAN:
            if −a.e < fbits(prec) then
                ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..0} || 0^{fbits(prec)+a.e}
            else
                lsb ← a.f_{-a.e-1-fbits(prec)+1..0} ≠ 0
                ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..-a.e-1-fbits(prec)+2} || lsb
            endif
        ZERO:
            ai ← a.s || 0^{ebits(prec)} || 0^{fbits(prec)}
        INFINITY:
            ai ← a.s || 1^{ebits(prec)} || 0^{fbits(prec)}
    endcase
defdef

def ai ← fsinkr(prec, a, round) as
    case a.t of
        NORM:
            msb ← findmsb(a.f)
            rb ← -a.e
            if rb ≤ 0 then
                aifr ← a.f_{msb..0} || 0^{-rb}
                aims ← msb - rb
            else
                case round of
                    C, C.D:
                        s ← 0^{msb-rb} || (~ai.s)^{rb}
                    F, F.D:
                        s ← 0^{msb-rb} || (ai.s)^{rb}
                    N, NONE:
                        s ← 0^{msb-rb} || ~ai.f_{rb} || ai.f_{rb}^{rb-1}
                    X:
                        if ai.f_{rb-1..0} ≠ 0 then
                            raise FloatingPointArithmetic // Inexact
                        endif
                        s ← 0
                    Z, Z.D:
                        s ← 0
```

FIG. 29-8

```
                endcase
                v ← (0||a.f_msb..0) + (0||s)
                if v_msb = 1 then
                        aims ← msb + 1 - rb
                else
                        aims ← msb - rb
                endif
                aifr ← v_aims..rb
            endif
            if aims > prec then
                case round of
                        C.D, F.D, NONE, Z.D:
                                ai ← a.s || (~as)^(prec-1)

                        C, F, N, X, Z:
                                raise FloatingPointArithmetic // Overflow
                endcase
            elseif a.s = 0 then
                ai ← aifr
            else
                ai ← -aifr
            endif
        ZERO:
            ai ← 0^prec
        SNAN, QNAN:
            case round of
                C.D, F.D, NONE, Z.D:
                        ai ← 0^prec
                C, F, N, X, Z:
                        raise FloatingPointArithmetic // Invalid
            endcase
        INFINITY:
            case round of
                C.D, F.D, NONE, Z.D:
                        ai ← a.s || (~as)^(prec-1)
                C, F, N, X, Z:
                        raise FloatingPointArithmetic // Invalid
            endcase
    endcase
enddef

def c ← frecrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fdiv(b,a))
enddef
```

FIG. 29-9

```
def c ← frsqrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fsqr(fdiv(b,a)))
enddef

def c ← fest(a) as
    if (a.t=NORM) then
        msb ← findmsb(a.f)
        a.e ← a.e + msb - 13
        a.f ← a.f_msb..msb-12 || 1
    else
        c ← a
    endif
enddef

def c ← fsqr(a) as
    if (a.t=NORM) and (a.s=0) then
        c.s ← 0
        c.t ← NORM
        if (a.e_0 = 1) then
            c.e ← (a.e-127) / 2
            c.f ← sqr(a.f || 0^127)
        else
            c.e ← (a.e-128) / 2
            c.f ← sqr(a.f || 0^128)
        endif
    elseif (a.t=SNAN) or (a.t=QNAN) or a.t=ZERO or ((a.t=INFINITY) and (a.s=0)) then
        c ← a
    elseif ((a.t=NORM) or (a.t=INFINITY)) and (a.s=1) then
        c ← DEFAULTSNAN // Invalid
    else
        assert FALSE // should have covered al the cases above
    endif
enddef
```

FIG. 29-10

Operation codes

E.ADD.F.16	Ensemble add floating-point half
E.ADD.F.16.C	Ensemble add floating-point half ceiling
E.ADD.F.16.F	Ensemble add floating-point half floor
E.ADD.F.16.N	Ensemble add floating-point half nearest
E.ADD.F.16.X	Ensemble add floating-point half exact
E.ADD.F.16.Z	Ensemble add floating-point half zero
E.ADD.F.32	Ensemble add floating-point single
E.ADD.F.32.C	Ensemble add floating-point single ceiling
E.ADD.F.32.F	Ensemble add floating-point single floor
E.ADD.F.32.N	Ensemble add floating-point single nearest
E.ADD.F.32.X	Ensemble add floating-point single exact
E.ADD.F.32.Z	Ensemble add floating-point single zero
E.ADD.F.64	Ensemble add floating-point double
E.ADD.F.64.C	Ensemble add floating-point double ceiling
E.ADD.F.64.F	Ensemble add floating-point double floor
E.ADD.F.64.N	Ensemble add floating-point double nearest
E.ADD.F.64.X	Ensemble add floating-point double exact
E.ADD.F.64.Z	Ensemble add floating-point double zero
E.ADD.F.128	Ensemble add floating-point quad
E.ADD.F.128.C	Ensemble add floating-point quad ceiling
E.ADD.F.128.F	Ensemble add floating-point quad floor
E.ADD.F.128.N	Ensemble add floating-point quad nearest
E.ADD.F.128.X	Ensemble add floating-point quad exact
E.ADD.F.128.Z	Ensemble add floating-point quad zero
E.DIV.F.16	Ensemble divide floating-point half
E.DIV.F.16.C	Ensemble divide floating-point half ceiling
E.DIV.F.16.F	Ensemble divide floating-point half floor
E.DIV.F.16.N	Ensemble divide floating-point half nearest
E.DIV.F.16.X	Ensemble divide floating-point half exact
E.DIV.F.16.Z	Ensemble divide floating-point half zero
E.DIV.F.32	Ensemble divide floating-point single
E.DIV.F.32.C	Ensemble divide floating-point single ceiling
E.DIV.F.32.F	Ensemble divide floating-point single floor
E.DIV.F.32.N	Ensemble divide floating-point single nearest
E.DIV.F.32.X	Ensemble divide floating-point single exact
E.DIV.F.32.Z	Ensemble divide floating-point single zero
E.DIV.F.64	Ensemble divide floating-point double

FIG. 30A-1

E.DIV.F.64.C	Ensemble divide floating-point double ceiling
E.DIV.F.64.F	Ensemble divide floating-point double floor
E.DIV.F.64.N	Ensemble divide floating-point double nearest
E.DIV.F.64.X	Ensemble divide floating-point double exact
E.DIV.F.64.Z	Ensemble divide floating-point double zero
E.DIV.F.128	Ensemble divide floating-point quad
E.DIV.F.128.C	Ensemble divide floating-point quad ceiling
E.DIV.F.128.F	Ensemble divide floating-point quad floor
E.DIV.F.128.N	Ensemble divide floating-point quad nearest
E.DIV.F.128.X	Ensemble divide floating-point quad exact
E.DIV.F.128.Z	Ensemble divide floating-point quad zero
E.MUL.C.F.16	Ensemble multiply complex floating-point half
E.MUL.C.F.32	Ensemble multiply complex floating-point single
E.MUL.C.F.64	Ensemble multiply complex floating-point double
E.MUL.F.16	Ensemble multiply floating-point half
E.MUL.F.16.C	Ensemble multiply floating-point half ceiling
E.MUL.F.16.F	Ensemble multiply floating-point half floor
E.MUL.F.16.N	Ensemble multiply floating-point half nearest
E.MUL.F.16.X	Ensemble multiply floating-point half exact
E.MUL.F.16.Z	Ensemble multiply floating-point half zero
E.MUL.F.32	Ensemble multiply floating-point single
E.MUL.F.32.C	Ensemble multiply floating-point single ceiling
E.MUL.F.32.F	Ensemble multiply floating-point single floor
E.MUL.F.32.N	Ensemble multiply floating-point single nearest
E.MUL.F.32.X	Ensemble multiply floating-point single exact
E.MUL.F.32.Z	Ensemble multiply floating-point single zero
E.MUL.F.64	Ensemble multiply floating-point double
E.MUL.F.64.C	Ensemble multiply floating-point double ceiling
E.MUL.F.64.F	Ensemble multiply floating-point double floor
E.MUL.F.64.N	Ensemble multiply floating-point double nearest
E.MUL.F.64.X	Ensemble multiply floating-point double exact
E.MUL.F.64.Z	Ensemble multiply floating-point double zero
E.MUL.F.128	Ensemble multiply floating-point quad
E.MUL.F.128.C	Ensemble multiply floating-point quad ceiling
E.MUL.F.128.F	Ensemble multiply floating-point quad floor
E.MUL.F.128.N	Ensemble multiply floating-point quad nearest
E.MUL.F.128.X	Ensemble multiply floating-point quad exact
E.MUL.F.128.Z	Ensemble multiply floating-point quad zero

FIG. 30A-2

Selection

class	op	prec				round/trap
add	EADDF	16	32	64	128	NONE C F N X Z
divide	EDIVF	16	32	64	128	NONE C F N X Z
multiply	EMULF	16	32	64	128	NONE C F N X Z
complex multiply	EMUL.CF	16	32	64		NONE

Format

E.op.prec.round   rd=rc,rb

rd=eopprecround(rc,rb)

31 … 24	23 … 18	17 … 12	11 … 6	5 … 0
E.prec	**rd**	**rc**	**rb**	**op.round**
8	6	6	6	6

FIG. 30B

Definition

```
def mul(size,v,i,w,j) as
    mul ← fmul(F(size,v_{size-1+i..i}),F(size,w_{size-1+j..j}))
enddef

def EnsembleFloatingPoint(op,prec,round,ra,rb,rc) as
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-prec by prec
        ci ← F(prec,c_{i+prec-1..i})
        bi ← F(prec,b_{i+prec-1..i})
        case op of
            E.ADD.F:
                ai ← faddr(ci,bi,round)
            E.MUL.F:
                ai ← fmul(ci,bi)
            E.MUL.C.F:
                if (i and prec) then
                    ai ← fadd(mul(prec,c,i,b,i-prec), mul(prec,c,i-prec,b,i))
                else
                    ai ← fsub(mul(prec,c,I,b,I), mul(prec,c,i+prec,b,i+prec))
                endif
            E.DIV.F.:
                ai ← fdiv(ci,bi)
        endcase
        a_{i+prec-1..i} ← PackF(prec, ai, round)
    endfor
    RegWrite(rd, 128, a)
enddef
```

FIG. 30C

Operation codes

E.SUB.F.16	Ensemble subtract floating-point half
E.SUB.F.16.C	Ensemble subtract floating-point half ceiling
E.SUB.F.16.F	Ensemble subtract floating-point half floor
E.SUB.F.16.N	Ensemble subtract floating-point half nearest
E.SUB.F.16.Z	Ensemble subtract floating-point half zero
E.SUB.F.16.X	Ensemble subtract floating-point half exact
E.SUB.F.32	Ensemble subtract floating-point single
E.SUB.F.32.C	Ensemble subtract floating-point single ceiling
E.SUB.F.32.F	Ensemble subtract floating-point single floor
E.SUB.F.32.N	Ensemble subtract floating-point single nearest
E.SUB.F.32.Z	Ensemble subtract floating-point single zero
E.SUB.F.32.X	Ensemble subtract floating-point single exact
E.SUB.F.64	Ensemble subtract floating-point double
E.SUB.F.64.C	Ensemble subtract floating-point double ceiling
E.SUB.F.64.F	Ensemble subtract floating-point double floor
E.SUB.F.64.N	Ensemble subtract floating-point double nearest
E.SUB.F.64.Z	Ensemble subtract floating-point double zero
E.SUB.F.64.X	Ensemble subtract floating-point double exact
E.SUB.F.128	Ensemble subtract floating-point quad
E.SUB.F.128.C	Ensemble subtract floating-point quad ceiling
E.SUB.F.128.F	Ensemble subtract floating-point quad floor
E.SUB.F.128.N	Ensemble subtract floating-point quad nearest
E.SUB.F.128.Z	Ensemble subtract floating-point quad zero
E.SUB.F.128.X	Ensemble subtract floating-point quad exact

FIG. 31A

Selection

class	op	prec	round/trap
set	SET. E LG L GE	16 32 64 128	NONE X
subtract	SUB	16 32 64 128	NONE C F N X Z

Format

E.op.prec.round rd=rb,rc

rd=eopprecround(rb,rc)

31 24	23 18	17 12	11 6	5 0
E.prec	**rd**	**rc**	**rb**	**op.round**
8	6	6	6	6

FIG. 31B

Definition

```
def EnsembleReversedFloatingPoint(op,prec,round,rd,rc,rb) as
	c ← RegRead(rc, 128)
	b ← RegRead(rb, 128)
	for i ← 0 to 128-prec by prec
		ci ← F(prec,c_{i+prec-1..i})
		bi ← F(prec,b_{i+prec-1..i})
		ai ← frsubr(ci,-bi, round)
		a_{i+prec-1..i} ← PackF(prec, ai, round)
	endfor
	RegWrite(rd, 128, a)
enddef
```

FIG. 31C

Operation codes

X.COMPRESS.2	Crossbar compress signed pecks
X.COMPRESS.4	Crossbar compress signed nibbles
X.COMPRESS.8	Crossbar compress signed bytes
X.COMPRESS.16	Crossbar compress signed doublets
X.COMPRESS.32	Crossbar compress signed quadlets
X.COMPRESS.64	Crossbar compress signed octlets
X.COMPRESS.128	Crossbar compress signed hexlet
X.COMPRESS.U.2	Crossbar compress unsigned pecks
X.COMPRESS.U.4	Crossbar compress unsigned nibbles
X.COMPRESS.U.8	Crossbar compress unsigned bytes
X.COMPRESS.U.16	Crossbar compress unsigned doublets
X.COMPRESS.U.32	Crossbar compress unsigned quadlets
X.COMPRESS.U.64	Crossbar compress unsigned octlets
X.COMPRESS.U.128	Crossbar compress unsigned hexlet
X.EXPAND.2	Crossbar expand signed pecks
X.EXPAND.4	Crossbar expand signed nibbles
X.EXPAND.8	Crossbar expand signed bytes
X.EXPAND.16	Crossbar expand signed doublets
X.EXPAND.32	Crossbar expand signed quadlets
X.EXPAND.64	Crossbar expand signed octlets
X.EXPAND.128	Crossbar expand signed hexlet
X.EXPAND.U.2	Crossbar expand unsigned pecks
X.EXPAND.U.4	Crossbar expand unsigned nibbles
X.EXPAND.U.8	Crossbar expand unsigned bytes
X.EXPAND.U.16	Crossbar expand unsigned doublets
X.EXPAND.U.32	Crossbar expand unsigned quadlets
X.EXPAND.U.64	Crossbar expand unsigned octlets
X.EXPAND.U.128	Crossbar expand unsigned hexlet
X.ROTL.2	Crossbar rotate left pecks
X.ROTL.4	Crossbar rotate left nibbles
X.ROTL.8	Crossbar rotate left bytes
X.ROTL.16	Crossbar rotate left doublets
X.ROTL.32	Crossbar rotate left quadlets
X.ROTL.64	Crossbar rotate left octlets
X.ROTL.128	Crossbar rotate left hexlet
X.ROTR.2	Crossbar rotate right pecks
X.ROTR.4	Crossbar rotate right nibbles
X.ROTR.8	Crossbar rotate right bytes
X.ROTR.16	Crossbar rotate right doublets

FIG. 32A-1

X.ROTR.32	Crossbar rotate right quadlets
X.ROTR.64	Crossbar rotate right octlets
X.ROTR.128	Crossbar rotate right hexlet
X.SHL.2	Crossbar shift left pecks
X.SHL.2.O	Crossbar shift left signed pecks check overflow
X.SHL.4	Crossbar shift left nibbles
X.SHL.4.O	Crossbar shift left signed nibbles check overflow
X.SHL.8	Crossbar shift left bytes
X.SHL.8.O	Crossbar shift left signed bytes check overflow
X.SHL.16	Crossbar shift left doublets
X.SHL.16.O	Crossbar shift left signed doublets check overflow
X.SHL.32	Crossbar shift left quadlets
X.SHL.32.O	Crossbar shift left signed quadlets check overflow
X.SHL.64	Crossbar shift left octlets
X.SHL.64.O	Crossbar shift left signed octlets check overflow
X.SHL.128	Crossbar shift left hexlet
X.SHL.128.O	Crossbar shift left signed hexlet check overflow
X.SHL.U.2.O	Crossbar shift left unsigned pecks check overflow
X.SHL.U.4.O	Crossbar shift left unsigned nibbles check overflow
X.SHL.U.8.O	Crossbar shift left unsigned bytes check overflow
X.SHL.U.16.O	Crossbar shift left unsigned doublets check overflow
X.SHL.U.32.O	Crossbar shift left unsigned quadlets check overflow
X.SHL.U.64.O	Crossbar shift left unsigned octlets check overflow
X.SHL.U.128.O	Crossbar shift left unsigned hexlet check overflow
X.SHR.2	Crossbar signed shift right pecks
X.SHR.4	Crossbar signed shift right nibbles
X.SHR.8	Crossbar signed shift right bytes
X.SHR.16	Crossbar signed shift right doublets
X.SHR.32	Crossbar signed shift right quadlets
X.SHR.64	Crossbar signed shift right octlets
X.SHR.128	Crossbar signed shift right hexlet
X.SHR.U.2	Crossbar shift right unsigned pecks
X.SHR.U.4	Crossbar shift right unsigned nibbles
X.SHR.U.8	Crossbar shift right unsigned bytes
X.SHR.U.16	Crossbar shift right unsigned doublets
X.SHR.U.32	Crossbar shift right unsigned quadlets
X.SHR.U.64	Crossbar shift right unsigned octlets
X.SHR.U.128	Crossbar shift right unsigned hexlet

FIG. 32A-2

Selection

class	op				size
precision	EXPAND		EXPAND.U		2 4 8 16 32 64 128
	COMPRESS		COMPRESS.U		
shift	ROTR	ROTL	SHR	SHL	2 4 8 16 32 64 128
	SHL.O	SHL.U.O	SHR.U		

Format

X.op.size rd=rc,rb

rd=xopsize(rc,rb)

31 2	24	23 18	17 12	11 6	5 1	
XSHIFT	**s**	**rd**	**rc**	**rb**	**op**	**sz**
7	1	6	6	6	4	2

lsize ← log(size)
s ← $lsize_2$
sz ← $lsize_{1..0}$

FIG. 32B

Definition

def Crossbar(op,size,rd,rc,rb)
  $c \leftarrow$ RegRead(rc, 128)
  $b \leftarrow$ RegRead(rb, 128)
  shift $\leftarrow$ b and (size-1)
  case $op_{5..2} \| 0^2$ of
    X.COMPRESS:
      hsize $\leftarrow$ size/2
      for i $\leftarrow$ 0 to 64-hsize by hsize
        if shift $\leq$ hsize then
          $a_{i+hsize-1..i} \leftarrow c_{i+i+shift+hsize-1..i+i+shift}$
        else
          $a_{i+hsize-1..i} \leftarrow c^{shift-hsize}_{i+i+size-1} \| c_{i+i+size-1..i+i+shift}$
        endif
      endfor
      $a_{127..64} \leftarrow 0$
    X.COMPRESS.U:
      hsize $\leftarrow$ size/2
      for i $\leftarrow$ 0 to 64-hsize by hsize
        if shift $\leq$ hsize then
          $a_{i+hsize-1..i} \leftarrow c_{i+i+shift+hsize-1..i+i+shift}$
        else
          $a_{i+hsize-1..i} \leftarrow 0^{shift-hsize} \| c_{i+i+size-1..i+i+shift}$
        endif
      endfor
      $a_{127..64} \leftarrow 0$
    X.EXPAND:
      hsize $\leftarrow$ size/2
      for i $\leftarrow$ 0 to 64-hsize by hsize
        if shift $\leq$ hsize then
          $a_{i+i+size-1..i+i} \leftarrow c^{hsize-shift}_{i+hsize-1} \| c_{i+hsize-1..i} \| 0^{shift}$
        else
          $a_{i+i+size-1..i+i} \leftarrow c_{i+size-shift-1..i} \| 0^{shift}$
        endif
      endfor

FIG. 32C-1

```
X.EXPAND.U:
        hsize ← size/2
        for i ← 0 to 64-hsize by hsize
            if shift ≤ hsize then
                a_{i+i+size-1..i+i} ← 0^{hsize-shift} || c_{i+hsize-1..i} || 0^{shift}
            else
                a_{i+i+size-1..i+i} ← c_{i+size-shift-1..i} || 0^{shift}
            endif
        endfor
    X.ROTL:
        for i ← 0 to 128-size by size
            a_{i+size-1..i} ← c_{i+size-1-shift..i} || c_{i+size-1..i+size-1-shift}
        endfor

X.ROTR:
    for i ← 0 to 128-size by size
        a_{i+size-1..i} ← c_{i+shift-1..i} || c_{i+size-1..i+shift}
    endfor
X.SHL:
    for i ← 0 to 128-size by size
        a_{i+size-1..i} ← c_{i+size-1-shift..i} || 0^{shift}
    endfor
X.SHL.O:
    for i ← 0 to 128-size by size
        if c_{i+size-1..i+size-1-shift} ≠ c^{shift+1}_{i+size-1-shift} then
            raise FixedPointArithmetic
        endif
        a_{i+size-1..i} ← c_{i+size-1-shift..i}|| 0^{shift}
    endfor
```

FIG. 32C-2

X.SHL.U.O:

for i ← 0 to 128-size by size

if $c_{i+size-1..i+size-shift} \neq 0^{shift}$ then

raise FixedPointArithmetic

endif

$a_{i+size-1..i} \leftarrow c_{i+size-1-shift..i} \| 0^{shift}$

endfor

X.SHR:

for i ← 0 to 128-size by size

$a_{i+size-1..i} \leftarrow c_{i+size-1}^{shift} \| c_{i+size-1..i+shift}$

endfor

X.SHR.U:

for i ← 0 to 128-size by size

$a_{i+size-1..i} \leftarrow 0^{shift} \| c_{i+size-1..i+shift}$

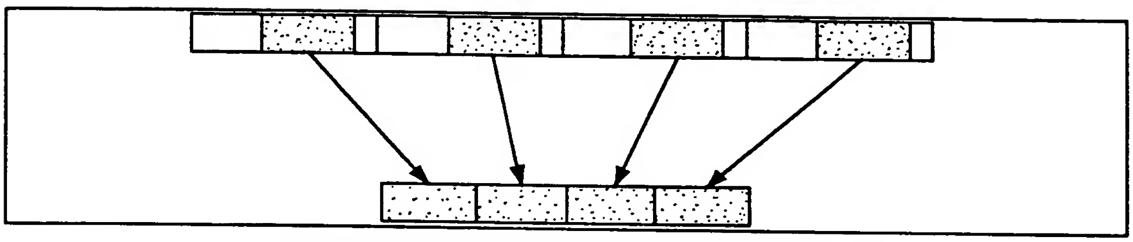
endfor

endcase

RegWrite(rd, 128, a)

enddef

FIG. 32C -3



Compress 32 bits to 16, with 4-bit right shift

FIG. 32D

Format

X.EXTRACT ra=rd,rc,rb

ra=xextract(rd,rc,rb)

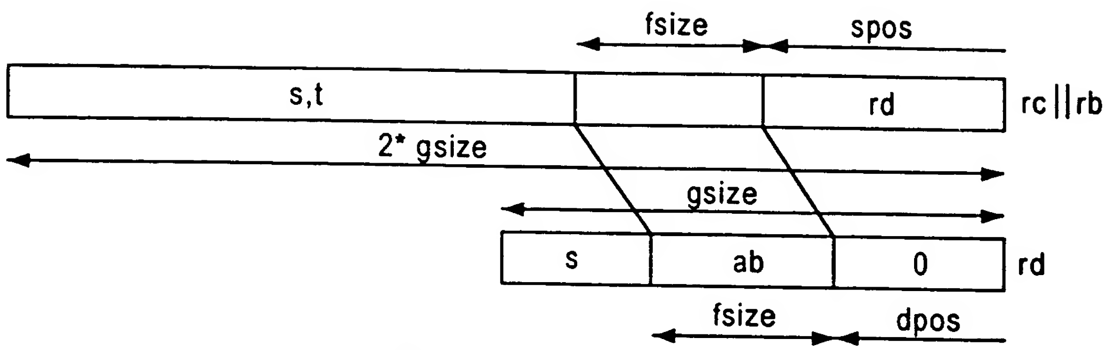
31 24	23 18	17 12	11 6	5 0
op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

FIG. 33A

Definition

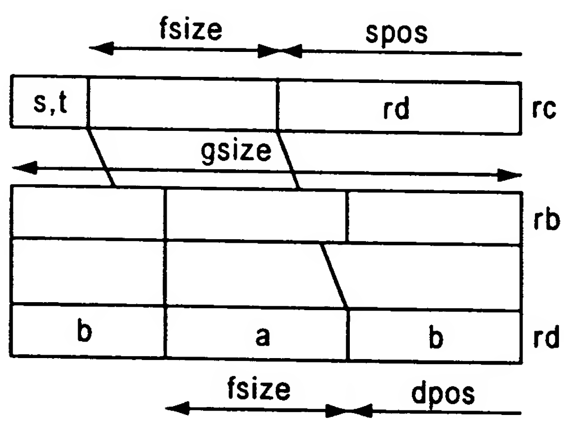
```
def CrossbarExtract(op,ra,rb,rc,rd) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case b8..0 of
        0..255:
            gsize ← 128
        256..383:
            gsize ← 64
        384..447:
            gsize ← 32
        448..479:
            gsize ← 16
        480..495:
            gsize ← 8
        496..503:
            gsize ← 4
        504..507:
            gsize ← 2
        508..511:
            gsize ← 1
    endcase
    m ← b12
    as ← signed ← b14
    h ← (2-m)*gsize
    spos ← (b8..0) and ((2-m)*gsize-1)
    dpos ← (0 || b23..16) and (gsize-1)
    sfsize ← (0 || b31..24) and (gsize-1)
    tfsize ← (sfsize = 0) or ((sfsize+dpos) > gsize) ? gsize-dpos : sfsize
    fsize ← (tfsize + spos > h) ? h - spos : tfsize
    for i ← 0 to 128-gsize by gsize
        case op of
            X.EXTRACT:
                if m then
                    p ← d_(gsize+i-1..i)
                else
                    p ← (d || c)_(2*(gsize+i)-1..2*i)
                endif
        endcase
        v ← (as & p_(h-1))||p
        w ← (as & v_(spos+fsize-1))^(gsize-fsize-dpos) || v_(fsize-1+spos..spos) || 0^dpos
        if m then
            a_(size-1+i..i) ← c_(gsize-1+i..dpos+fsize+i) || w_(dpos+fsize-1..dpos) || c_(dpos-1+1..i)
        else
            a_(size-1+i..i) ← w
        endif
    endfor
    RegWrite(ra, 128, a)
enddef
```

FIG. 33B



Crossbar extract

FIG. 33C



Crossbar merge extract

FIG. 33D

X.SHUFFLE.4	Crossbar shuffle within pecks
X.SHUFFLE.8	Crossbar shuffle within bytes
X.SHUFFLE.16	Crossbar shuffle within doublets
X.SHUFFLE.32	Crossbar shuffle within quadlets
X.SHUFFLE.64	Crossbar shuffle within octlets
X.SHUFFLE.128	Crossbar shuffle within hexlet
X.SHUFFLE.256	Crossbar shuffle within triclet

FIG. 34A

Format

X.SHUFFLE.256 rd=rc,rb,v,w,h
X.SHUFFLE.size rd=rcb,v,w

rd=xshuffle256(rc,rb,v,w,h)
rd=xshufflesize(rcb,v,w)

31 24	23 18	17 12	11 6	5 0
X.SHUFFLE	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

$rc \leftarrow rb \leftarrow rcb$
$x \leftarrow \log_2(size)$
$y \leftarrow \log_2(v)$
$z \leftarrow \log_2(w)$
$op \leftarrow ((x*x*x-3*x*x-4*x)/6-(z*z-z)/2+x*z+y) + (size=256)*(h*32-56)$

FIG. 34B

Definition

```
def CrossbarShuffle(major,rd,rc,rb,op)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    if rc=rb then
        case op of
            0..55:
                for x ← 2 to 7; for y ← 0 to x-2; for z ← 1 to x-y-1
                    if op = ((x*x*x-3*x*x-4*x)/6-(z*z-z)/2+x*z+y) then
                        for i ← 0 to 127
                            a_i ← c(i_6..x || i_y+z-1..y || i_x-1..y+z || i_y-1..0)
                        end
                    endif
                endfor; endfor; endfor
            56..63:
                raise ReservedInstruction
        endcase
    elseif
        case op_4..0 of
            0..27:
                cb ← c || b
                x ← 8
                h ← op_5
                for y ← 0 to x-2; for z ← 1 to x-y-1
                    if op_4..0 = ((17*z-z*z)/2-8+y) then
                        for i ← h*128 to 127+h*128
                            a_i-h*128 ← cb(i_y+z-1..y || i_x-1..y+z || i_y-1..0)
                        end
                    endif
                endfor; endfor
            28..31:
                raise ReservedInstruction
        endcase
    endif
    RegWrite(rd, 128, a)
enddef
```

FIG. 34C

Figure 35A

Wide Solve Galois

wminor	*galpoly	*galpoly	solv par	wsolv g
8	6	6	6	6

Solves L*S =W mod z**8 in 8 iterations

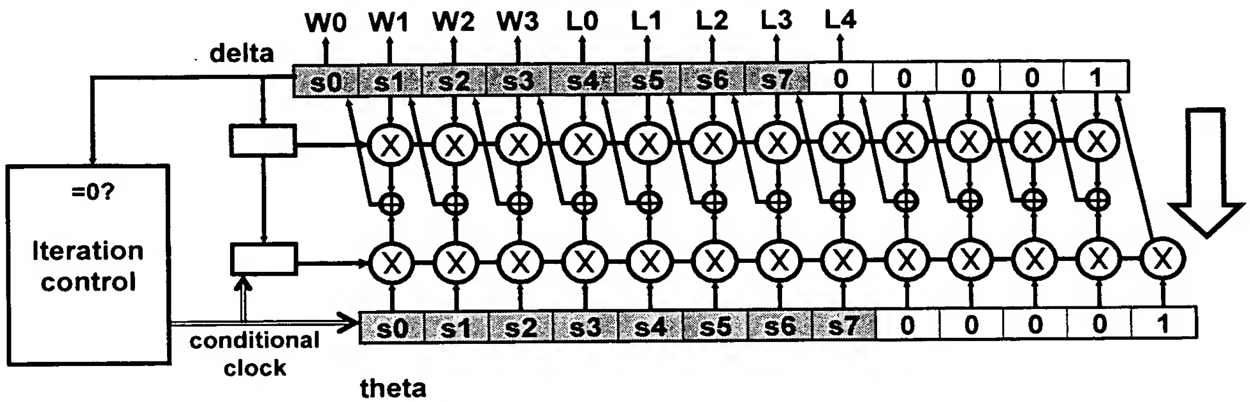


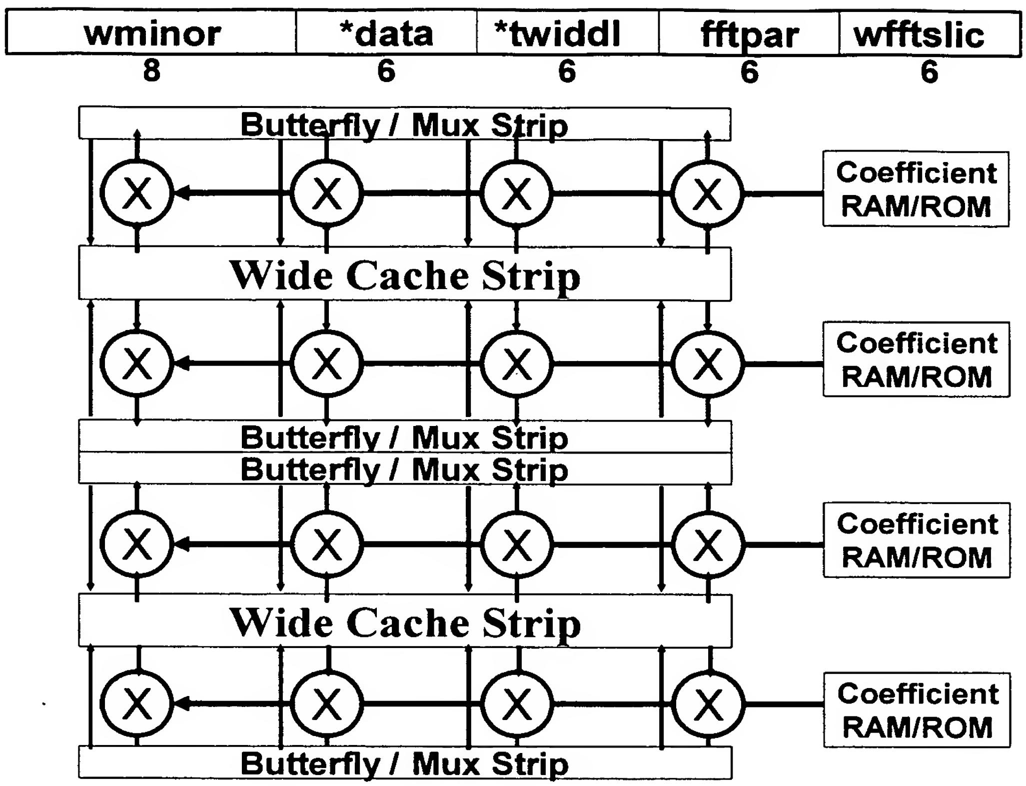
Figure 35B

Wide Solve Galois

```
static      v8_t      wsolveg(v8_t hh, v8_t syndrome, v8_t *omega)

for ( r=0; r < N_PARITY; r++)                                                    /*: A + 16*(B+A):*/
  {
   delta = _xcopyi8(delta0,0);                                                          /*: 16*X :*/
   delta0s = _castv8(_xshrm128(_castv128(delta0),_castv128(delta1),8));                 /*: 16*X :*/
   delta1s = _reindex8(delta1, -1);                                                     /*: 16*X :*/
   delta0 = _gxor8(_emulg8(gamma, delta0s, hh),_emulg8(delta,theta0, hh));              /*: 16*(2*E+G) :*/
   delta1 = _gxor8(_emulg8(gamma, delta1s, hh),_emulg8(delta,theta1, hh));              /*: 16*(2*E+G) :*/
   s = _gsetandne8(delta, _gsetge8(k,_gzero8));                                         /*: 16*2*G :*/
   theta0 = _gmux8(s,delta0s,theta0);                                                   /*: 16*G :*/
   theta1 = _gmux8(s,delta1s,theta1);                                                   /*: 16*G :*/
   gamma = _gmux8(s,delta,gamma);                                                       /*: 16*G :*/
   k = _gmux8(s,_gnot8(k),_gadd8(k,_gone8));                                            /*: 16*3*G :*/
  }
  lambda = _xselect8(delta1,delta0,USE_VCONST(lambdai));                                /*: X :*/
  *omega = _castv8(_xwithdrawu128(_castv128(delta0),64,0));                             /*: X :*/
```

Figure 36A

Wide FFT Slice



```
/****************************************************************************/
/* DSP library module :  Inverse FFT, selectable length,            */
/*                                16-bit complex integers,          */
/*                                split-radix algorithm                  */
/*                                                                   */
/****************************************************************************/

/* include files */
#include <stdio.h>
#include "broadmx.h"
#include "affirm.h"
#include "dspFFTud.h"
#include <math.h>

#define  SHOW           0


/* typed version of _gboolean: should be part of gops */
static INLINE v16_t        _gboolean16(v16_t src1, v16_t src2, v16_t src3, int imm)
{
 return _gboolean(src1.rr, src2.rr, src3.rr, imm).v16;
}

/*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 * I * (a - b) / 2
 */
static     inline    vc16_t   _sub_mul_by_i_c16(vc16_t aa, vc16_t bb)
{
  v16_t muxmask          = _castv16(_gcopyi32(0xFFFF));
  v16_t xx;

  /* xx = _gsubh16n(_gmux16(muxmask,aa,bb),_gmux16(muxmask,bb,aa)); */
  xx = _gsubh16n(_gxor16(muxmask,bb),_gxor16(muxmask,aa));
  xx = _xswizzle16(xx, 7, 1);
  return xx;
}
```

Fig. 36B

```
/*----------------------------------------
 * Perform 4 independent 4-point fft's
 *
 * x0..x3 holds the input to the transform, 4 sets of 4 complex numbers.
 * Each set is inverse-fourier transformed independently of the others.
 * The results appear in x0..x3.  The original values of y0..y3 are corrupted.
 */
#define  QUAD_IFFT_4PT_c16(_y0,_y1,_y2,_y3,  _x0,_x1,_x2,_x3)  { \
   _y0 = _gaddh16n(_x0,_x2);                \
   _y1 = _gaddh16n(_x1,_x3);                \
   _y2 = _gsubh16n(_x0,_x2);                \
   _y3 = _sub_mul_by_i_c16(_x1,_x3);        \
   _x0 = _gaddh16n(_y0,_y1);                \
   _x2 = _gsubh16n(_y0,_y1);                \
   _x1 = _gaddh16n(_y2,_y3);                \
   _x3 = _gsubh16n(_y2,_y3);                \
}

/*----------------------------------------
 * Perform 4 independent 2-point fft's
 *
 * x0..x1 holds the input to the transform, 4 sets of 2 complex numbers.
 * Each set is inverse-fourier transformed independently of the others.
 * The results appear in y0..y1.
 */
#define  QUAD_IFFT_2PT_c16(_y0,_y1,  _x0,_x1)  { \
   _y0 = _gaddh16n(_x0,_x1);                \
   _y1 = _gsubh16n(_x0,_x1);                \
}
```

Fig. 36B (cont)

```
static int _wfftslicec16(vc16_t *dp, vc16_t *tp, int dn, int ds, int tn, int radix, int reorder, int extract)
{
 int i,j,ii, logmost;
 vc16_t *dwp, *twp;
 vc16_t t0,t1,t2,t3, d0,d1,d2,d3, p0,p1,p2,p3, z0,z1,z2,z3, m, n;

 if(SHOW) printf("extract = %d\n",extract&0xf);
 n = m = _gcopyi16(0);
 if (radix==4) {
  if (ds==1) {
   for (twp=tp,i=0; i<tn; dp++,twp++,i+=NELEMC16) {
        t0 = twp[0];
        d0 = dp[0];
        p0 = _emulx16(t0,d0,extract);
        z0 = _xshri16(p0,1);
        n = _gboolean16(n,p0,z0,0xf6);
        d0 = _vput16(d0,0,(_vget16(p0,0)+_vget16(p0,2)+_vget16(p0,4)+_vget16(p0,6)+2)>>2);
        d0 = _vput16(d0,1,(_vget16(p0,1)+_vget16(p0,3)+_vget16(p0,5)+_vget16(p0,7)+2)>>2);
        d0 = _vput16(d0,4,(_vget16(p0,0)-_vget16(p0,2)+_vget16(p0,4)-_vget16(p0,6)+2)>>2);
        d0 = _vput16(d0,5,(_vget16(p0,1)-_vget16(p0,3)+_vget16(p0,5)-_vget16(p0,7)+2)>>2);
        d0 = _vput16(d0,2,(_vget16(p0,0)-_vget16(p0,3)-_vget16(p0,4)+_vget16(p0,7)+2)>>2);
        d0 = _vput16(d0,3,(_vget16(p0,1)+_vget16(p0,2)-_vget16(p0,5)-_vget16(p0,6)+2)>>2);
        d0 = _vput16(d0,6,(_vget16(p0,0)+_vget16(p0,3)-_vget16(p0,4)-_vget16(p0,7)+2)>>2);
        d0 = _vput16(d0,7,(_vget16(p0,1)-_vget16(p0,2)-_vget16(p0,5)+_vget16(p0,6)+2)>>2);
        z0 = _xshri16(d0,1);
        m = _gboolean16(m,d0,z0,0xf6);
        dp[0] = d0;
   }
  } else {
   ii = ds / NELEMC16;
   for (twp=tp,i=0; i<tn; dp++,twp++,i+=4*NELEMC16) {
        t0 = twp[0*ii];
        t1 = twp[1*ii];
        t2 = twp[2*ii];
        t3 = twp[3*ii];
        for (dwp=dp,j=0; j<dn; dwp+=4*ii,j+=4*ds) {
         d0 = dwp[0*ii];
         d1 = dwp[1*ii];
         d2 = dwp[2*ii];
         d3 = dwp[3*ii];
         d0 = _emulx16(t0,d0,extract); // can be eextract
         d1 = _emulx16(t1,d1,extract);
         d2 = _emulx16(t2,d2,extract);
         d3 = _emulx16(t3,d3,extract);
         z0 = _xshri16(d0,1);
         z1 = _xshri16(d1,1);
         z2 = _xshri16(d2,1);
         z3 = _xshri16(d3,1);
         n = _gboolean16(n,d0,z0,0xf6);
         n = _gboolean16(n,d1,z1,0xf6);
         n = _gboolean16(n,d2,z2,0xf6);
         n = _gboolean16(n,d3,z3,0xf6);
```

Fig. 36B (cont)

```
          QUAD_IFFT_4PT_c16(p0,p1,p2,p3, d0,d1,d2,d3);
          z0 = _xshri16(d0,1);
          z1 = _xshri16(d1,1);
          z2 = _xshri16(d2,1);
          z3 = _xshri16(d3,1);
          m = _gboolean16(m,d0,z0,0xf6);
          m = _gboolean16(m,d1,z1,0xf6);
          m = _gboolean16(m,d2,z2,0xf6);
          m = _gboolean16(m,d3,z3,0xf6);
          dwp[0*ii] = d0;
          dwp[1*ii] = d1;
          dwp[2*ii] = d2;
          dwp[3*ii] = d3;
         }
    }
   }
  } else if (radix==2) {
   ii = ds / NELEMC16;
   for (twp=tp,i=0; i<tn; dp++,twp++,i+=2*NELEMC16) {
    t0 = twp[0*ii];
    t1 = twp[1*ii];
    for (dwp=dp,j=0; j<dn; dwp+=2*ii,j+=2*ds) {
         d0 = dwp[0*ii];
         d1 = dwp[1*ii];
         p0 = _emulx16(t0,d0,extract); // can be eextract
         p1 = _emulx16(t1,d1,extract);
         z0 = _xshri16(p0,1);
         z1 = _xshri16(p1,1);
         n = _gboolean16(n,p0,z0,0xf6);
         n = _gboolean16(n,p1,z1,0xf6);
         QUAD_IFFT_2PT_c16(d0,d1, p0,p1);
         z0 = _xshri16(d0,1);
         z1 = _xshri16(d1,1);
         m = _gboolean16(m,d0,z0,0xf6);
         m = _gboolean16(m,d1,z1,0xf6);
         dwp[0*ii] = d0;
         dwp[1*ii] = d1;
    }
   }
  } else {
    for (j=0; j<dn; dp++,tp++,j+=NELEMC16) {
         *dp = d0 = *tp;
         z0 = _xshri16(d0,1);
         m = _gboolean16(m,d0,z0,0xf6);
    }
    n = m;
  }
```

Fig. 36B (cont)

```
 n = _gor16(n,_castv16(_xshriu128(_castv128(n),64)));
 n = _gor16(n,_castv16(_xshriu128(_castv128(n),32)));
 n = _gor16(n,_castv16(_xshriu128(_castv128(n),16)));
 logmost = _vget16(_elogmost16(n),0);
 if(SHOW) printf("logmost = %d (after mulx)\n",logmost);
 m = _gor16(m,_castv16(_xshriu128(_castv128(m),64)));
 m = _gor16(m,_castv16(_xshriu128(_castv128(m),32)));
 m = _gor16(m,_castv16(_xshriu128(_castv128(m),16)));
 logmost = _vget16(_elogmost16(m),0);
 if(SHOW) printf("logmost = %d (after addh)\n",logmost);
 return logmost;
}

static     cplxi16  const     exptab[][4] =
#define IFFT_COEFS_16
#include "dspIFFT-coefs.h"
#undef IFFT_COEFS_16
;

static     void      make_twiddle(cplxi16 *tw, int ni, int nj, int len, int show)
{
   int                ii, jj;

   for(ii = 0;  ii < ni;  ++ii) {
          for(jj = 0;  jj < nj;  ++jj) {
             tw->re = rint(-32768*cos(2*M_PI/len*ii*jj));
             tw->im = rint(-32768*sin(2*M_PI/len*ii*jj));
             if(show) printf("twiddle[%d][%d] = (%7d,%7d)\n", ii, jj,  tw->re, tw->im);
             ++tw;
          }
   }
}

int dspInverseFourier_slice_c16(cplxi16 *out, cplxi16 const *in, int len)
{
  int logmost, extract, scale;
  static cplxi16 twidtab[12][1024];
  int i, j, k, l;
  int ds, tn;

  for(i = 0; i < len;  ++i) {
          twidtab[0][i].re = -32768;
          twidtab[0][i].im = 0;
  }
  make_twiddle(&twidtab[1][0], 4, 4, 16, 0);
  make_twiddle(&twidtab[2][0], 4, 16, 64, 0);
  make_twiddle(&twidtab[3][0], 4, 64, 256, 0);
  make_twiddle(&twidtab[4][0], 2, 256, 512, 0);
```
Fig. 36B (cont)

```
scale = 0;
logmost = 0;
 if(len == 4) {
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)in, len, 0, 0, 1, 0, 0);
        scale = 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[0], len, 1, len, 4, 0, extract);
 } else if(len == 16) {
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)in, len, 0, 0, 1, 0, 0);
        scale = 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[0], len, 1, len, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[1], len, 4, 16, 4, 0, extract);
 } else if(len == 64) {
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)in, len, 0, 0, 1, 0, 0);
        scale = 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[0], len, 1, len, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[1], len, 4, 16, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[2], len, 16, 64, 4, 0, extract);
        scale -= 2;
 } else if(len == 256) {
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)in, len, 0, 0, 1, 0, 0);
        scale = 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[0], len, 1, len, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[1], len, 4, 16, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[2], len, 16, 64, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[3], len, 64, 256, 4, 0, extract);
        scale -= 4;
```

Fig. 36B (cont)

```
} else if(len == 512) {
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)in, len, 0, 0, 1, 0, 0);
        scale = 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[0], len, 1, len, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[1], len, 4, 16, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[2], len, 16, 64, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[3], len, 64, 256, 4, 0, extract);
        scale += 16 - logmost;
        extract = (1<<14) + (1<<13) + (2<<9) + (512-4*16+logmost+1);
        logmost = _wfftslicec16((vc16_t *)out, (vc16_t *)twidtab[4], len, 256, 512, 2, 0, extract);
        scale -= 7;
  }
  if(SHOW) printf("scale = %d\n",scale);
  return scale;
```

Fig. 36B (cont)

Format

W.CONVOLVE.X.order ra=rc,rd,rb

ra=wop(rc,rd,rb)

31 24	23 18	17 12	11 6	5 0
W.op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 37A

Definition

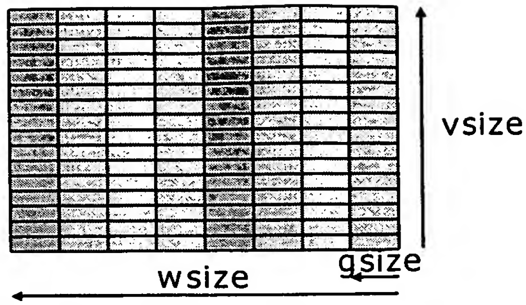
```
def mul(size,h,vs,v,i,ws,w,j) as
	mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def WideConvolveExtract(op,ra,rb,rc,rd)
	d ← RegRead(rd, 64)
	c ← RegRead(rc, 64)
	b ← RegRead(rb, 128)
	case b_{8..0} of
		0..255:
			sgsize ← 128
		256..383:
			sgsize ← 64
		384..447:
			sgsize ← 32
		448..479:
			sgsize ← 16
		480..495:
			sgsize ← 8
		496..503:
			sgsize ← 4
		504..507:
			sgsize ← 2
		508..511:
			sgsize ← 1
	endcase
	l ← b_11
	m ← b_12
	n ← b_13
	signed ← b_14
	x ← b_15
	if (c_{2..0} ≠ 0) or (d_{2..0} ≠ 0) then
		raise ReservedInstruction
	endif
	cwsize ← (c and (0-c)) || 0^5
	ct ← c and (c-1)
	cmsize ← (ct and (0-ct)) || 0^4
	ca ← ct and (ct-1)
	lcmsize ← log(cmsize)
	lcwsize ← log(cwsize)
	cm ← LoadMemory(c,ca,cmsize,order)
	dwsize ← (d and (0-d)) || 0^5
	dt ← d and (d-1)
	dmsize ← (dt and (0-dt)) || 0^4
	da ← dt and (dt-1)
	ldmsize ← log(dmsize)
	ldwsize ← log(dwsize)
	dm ← LoadMemory(d,da,dmsize,order)
	if (sgsize < 8) or (sgsize > wsize/2) then
		raise ReservedInstruction
```

```
endif
gsize ← sgsize
lgsize ← log(gsize)
case op of
        W.CONVOLVE.X.B:
                order ← B
        W.CONVOLVE.X.L:
                order ← L
endcase
cs ← signed
ds ← signed ^ m
zs ← signed or m or n
zsize ← gsize*(x+1)
h ← (2*gsize) + ldmsize - lgsize
spos ← (b8..0) and (2*gsize-1)
dpos ← (0 || b23..16) and (zsize-1)
r ← spos
sfsize ← (0 || b31..24) and (zsize-1)
tfsize ← (sfsize = 0) or ((sfsize+dpos) > zsize) ? zsize-dpos : sfsize
fsize ← (tfsize + spos > h+1) ? h+1 - spos : tfsize
if (b10..9 = Z) and not zs then
        rnd ← F
else
        rnd ← b10..9
endif
mzero ← b95..64
mpos ← b63..32
oo ← mpos || 0^3
ox ← oo_lcwsize-1..lgsize
oy ← oo_lcmsize-1..lcwsize
zz ← (~mzero) || 1^3
zx ← zz_ldwsize-1..lgsize
zy ← zz_ldmsize-1..ldwsize
```

Fig. 37B (cont)

```
for k ← 0 to 128-zsize by zsize
        i ← k*gsize/zsize
        ix ← i_{lcwsize-1..lgsize}
        iy ← i_{lcmsize-1..lcwsize}
        q[0] ← 0^h
        for j ← 0 to dmsize-gsize by gsize
                jj ← n and j_{lgsize} and not i_{lgsize}
                jx ← j_{ldwsize-1..lgsize}
                jy ← j_{ldmsize-1..ldwsize}
                u ← (oy+iy-jy)_{lcmsize-lcwsize-1..0} || (ox+ix-jx-2*jj)_{lcmsize-lcwsize-1..0} || 0^{lgsize}
                if (jx>zx) or (jy>zy) and (dm_{lgsize-1+j..j}0 ) and undefined then
                        q[j+gsize] ← q[j]
                else
                        if jj then
                                q[j+gsize] ← q[j] - mul(gsize,h,cs,cm,u,ds,dm,j)
                        else
                                q[j+gsize] ← q[j] + mul(gsize,h,cs,cm,u,ds,dm,j)
                        endif
                endif
        endfor
        p ← q[dmsize]
        case rnd of
                none, N:
                        s ← 0^{h-r} || ~p_r || ~p_r^{r-1}
                Z:
                        s ← 0^{h-r} || p_{h-1}^r
                F:
                        s ← 0^h
                C:
                        s ← 0^{h-r} || 1^r
        endcase
        v ← ((zs & p_{h-1})||p) + (0||s)
        if (v_{h..r+fsize} = (zs & v_{r+fsize-1})^{h+1-r-fsize}) or not l then
                w ← (zs & v_{r+fsize-1})^{zsize-fsize-dpos} || v_{fsize-1+r..r} || 0^{dpos}
        else
                w ← (zs ? (v_h^{zsize-fsize-dpos+1}||~v_h^{fsize-1}) : 0^{zsize-fsize-dpos}||1^{fsize}) || 0^{dpos}
        endif
        z_{zsize-1+k..k} ← w
endfor
RegWrite(ra, 128, z)
enddef
```

Fig. 37B

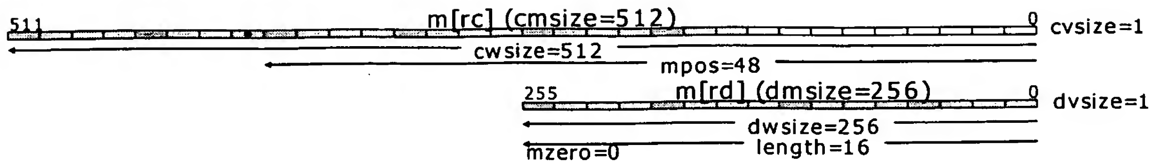


msize = wsize * vsize

spec = base + msize/16 + wsize/32

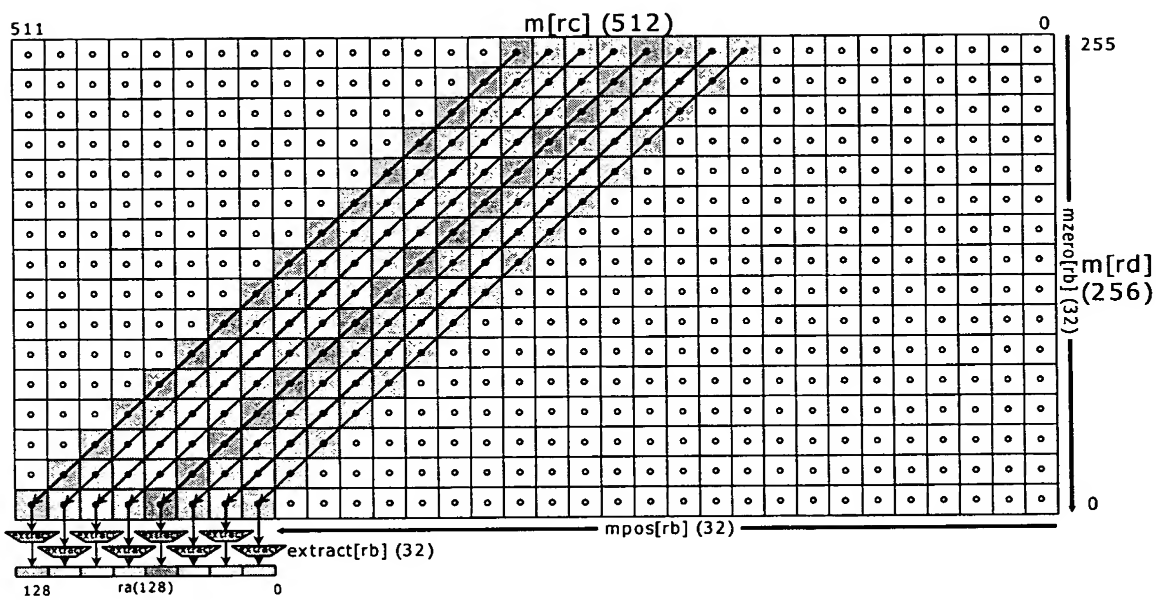
Wide operand specifier for wide convolve extract

Fig. 37C



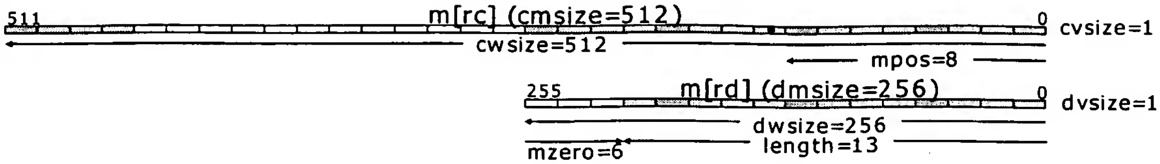
Wide convolve extract doublets

Fig. 37D



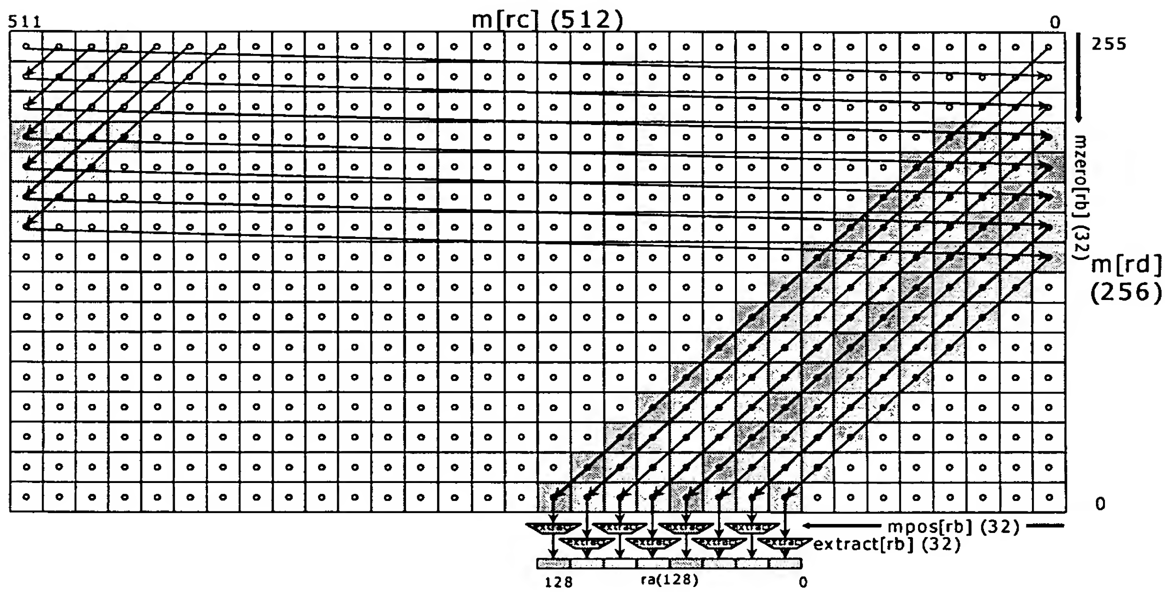
Wide convolve extract doublets

Fig. 37E



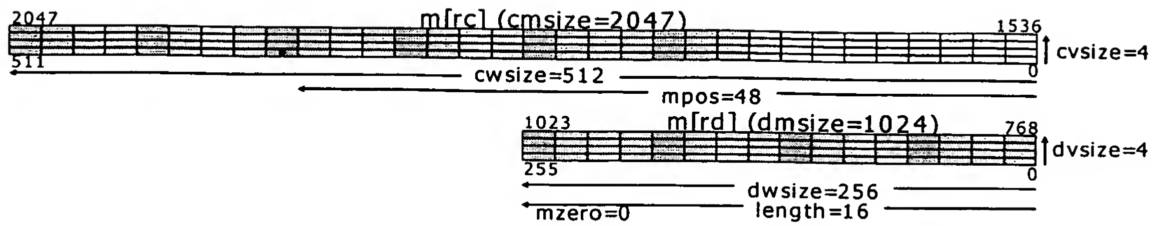
Wide convolve extract doublets

Fig. 37F



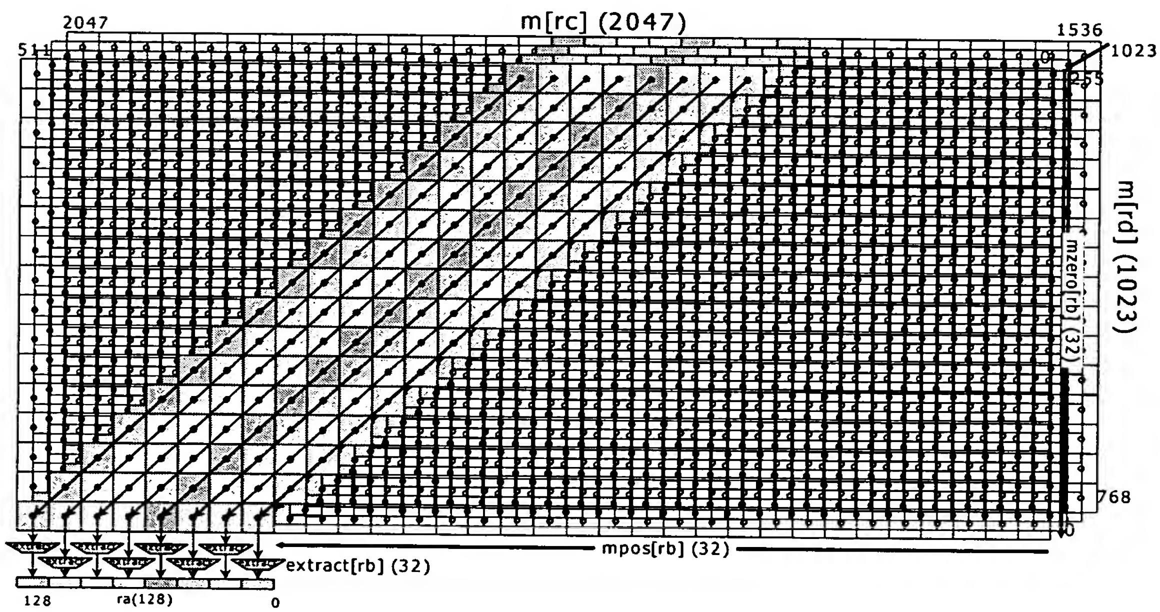
Wide convolve extract doublets

Fig. 37G



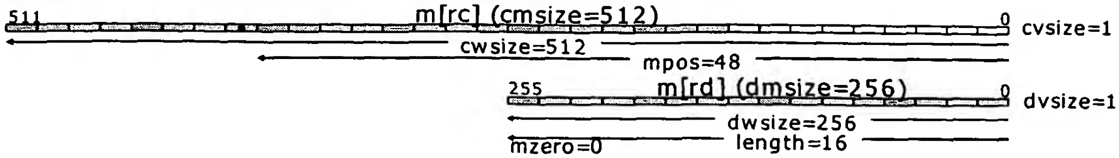
Wide convolve extract doublets two-dimensional

Fig. 37H



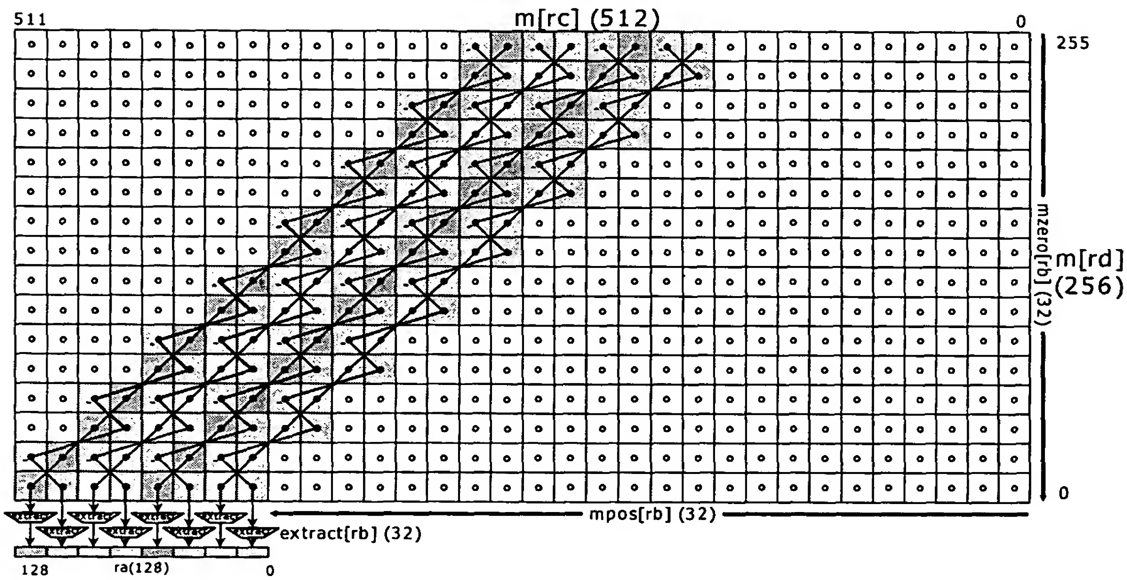
Wide convolve extract doublets two-dimensional

Fig. 37I



Wide convolve extract complex doublets

Fig. 37J



Wide convolve extract complex doublets

Fig. 37K

Figure 38 **Wide Embedded Cache Coherency**